PHD

The ecology and behaviour of Rattus species in relation to the yield of coconuts and cocoa in Fiji.

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THE ECOLOGY AND BEHAVIOUR OF *RATTUS* SPECIES

IN RELATION TO THE YIELD OF COCONUTS

AND COCOA IN FIJI

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STATEMENT

SPELLING AND PRONUNCIATION OF FIJIAN NAMES.

A "Fijian" system of spelling was devised during the period 1835 - 37 by the Missionaries who first reduced the Fijian language to writing. They aimed at representing the various Fijian sounds by single letters and the system that resulted has been used ever since by the Fijian people and is in general use throughout Fiji. The letters concerned are "b", "c", "g" and "q" and the following examples indicate the manner in which they are pronounced.

(i) B is pronounced "MB" as in number e.g. LABASA = LAMBASA

(ii) C is pronounced "TH" as in that, e.g. CAUTATA = THAUTATA

(iii) D is pronounced "ND" as in end, e.g. NADI = NANDI

(iv) G is pronounced "NG" as in sing, e.g. SIGATOKA = SINGATOKA

(v) Q is pronounced "NGG" as in finger, e.g. YAQARA = YANGGARA

In practically all words in Fijian, the accent is on the penultimate syllable.

The "Fijian" system of spelling is used in this thesis.

PUBLICATIONS

Some of the work reported in this thesis has been published:-

(i) WILLIAMS, J.M. (1971) Assessing the effect of rat damage on coconut yields. Fiji Agric. J. 33: 55 - 56.

(ii WILLIAMS, J.M. (1973) Rat damage assessment and control in cocoa. Fiji Agric. J. 35: 15 - 25.

(iii WILLIAMS, J.M. (1974) Rat damage to coconuts in Fiji. Part I. Assessment of damage. P.A.N.S. 20 (3 - 4 In press.

(iv WILLIAMS, J.M. (1974). Rat damage to coconuts in Fiji. Part 2. Efficiency and economics of damage reduction methods. P.A.N.S. 20 (3 -4 . In press.

(v WILLIAMS, J.M. (1974). The effect of artificial rat damage on coconut yields in Fiji. P.A.N.S. 20 (3 - 4 . In press.

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Finally I wish to express deep appreciation to Pamela for encouragement and assistance in all spheres of the research programme over the last five years.

SUMMARY

The studies described in this thesis sought to establish the importance of Rattus exulans and Rattus rattus as pests of two crops, coconuts and cocoa, in Fiji.

Movement patterns of R. exulans were investigated. Males moved greater distances in both crops with distances increasing with population density.

The eye-lens technique proved to be useful for ageing rats up to about 100 days.

Population levels fluctuated considerably at all sites but there was no marked seasonal trend. No simple relationship existed between rat densities and damage to the two crops. Damage only increased when marked population peaks coincided with a possible shortage of other sources of food.

Both species attacked developing coconuts but R. rattus caused most damage because it foraged more extensively in the crowns of taller palms. R. rattus also caused most damage to cocoa despite both species being in constant contact with the crop. Attack of cocoa appeared to be a learned pattern of behaviour.

Coconut damage and production was surveyed at 16 sites over three years. Damage varied considerably between palms, sites and years. Rats favoured coconuts aged three to seven months, stages of development during which sugar concentrations were highest. Because coconuts on particular palms were favoured a possible basis for this palm selection was sought.

Despite concentration of attack, favoured palms did not produce fewer mature coconuts. A trial simulating rat damage established that the coconut palm was capable of compensating for

the premature removal of nuts. Compensation was conservatively estimated to replace 50 percent of the nuts lost.

Control of rat damage to coconuts in Fiji was not economical because of the low level of loss after compensation and the inefficiency of trunk banding, the most convenient method of reducing damage.

Damage to cocoa was serious at some localities. No compensation occurred but control, using warfarin based baits, proved highly economical.

INTRODUCTION

Chapter 1

1.1 ORIGIN AND AIMS OF THE STUDY

In April 1969 I was appointed to a new post, within the Research Division of the Fiji Department of Agriculture, established to enable investigation of vertebrate damage in Fiji crops.

The position's terms of reference were very broad due to the lack of information on vertebrate pests. Rat and bird damage to crops and possible methods of control were to be investigated as well as the basic ecology of the attacking species.

Before establishing a detailed work programme a preliminary tour of the south coast of Vanua Levu and Taveuni was made for this area produces 50-60 percent (McPaul, 1963) of Fiji's total copra production and rat damage to coconuts was high in the area during the 1930's (Paine, 1934). In addition a visit was made to Funafuti in the Ellice Islands where field methods were discussed with Mr. F.J. Smith, who was carrying out a survey of rat damage in the Gilbert and Ellice Islands. Research priorities were also discussed with E.J. Wilson, the South Pacific Commission Rodent Control Officer.

Discussions with plantation owners, agricultural officers and other research workers familiar with Fiji's major crops confirmed that rat attack of coconuts was thought to be causing a significant reduction in yield. Some plantation owners expressed concern at the cost of banding palm trunks with aluminium (the recommended method of reducing rat damage) and doubted that there was any significant increase in the number of coconuts produced.

Cocoa research programmes established in 1968 (Vernon, unpublished report) had revealed that the rat was a serious pest of this crop despite there having been no discussion of the pest in an extensive review of the industry in 1959 (Harwood et al., 1959). In contrast to cocoa, rats were not considered by the research and field staff of South Pacific Sugar Mills, to be a significant pest of sugar cane.

Following the preliminary tours, discussions and references to relevant literature it was agreed that the research programme should be concentrated on rat damage problems in coconut and cocoa crops. A series of projects were designed to yield information on the nature and extent of rat damage to coconuts and cocoa, the ecology of the rat populations involved and efficiency of available control techniques.

The collective aim of the projects was to provide:-

(a) Information on Rattus biology relevant to a crop protection study, that is , species responsible for damage, species distribution, population densities movements, breeding periodicity, reproduction rates, age structure and possible reasons for attacking the two crops.

(b) An accurate assessment of the amount of damage caused by rats in the two crops and the relationship of this damage to actual production losses.

(c) Data on the efficiency and economics of suitable control measures in the two crops.

In terms of priorities the whole research programme essentially consisted of three parts: damage assessment, ecological studies and control studies. All aspects were, of necessity, worked on at the same time but emphasis was initially on the first two aspects for without an adequate body of information in those spheres control studies could have been a waste of time.

It should be noted that the whole programme of research was developed in response to a need within an agricultural community and therefore the work planned had to cover a very broad field of research. Crop damage asssessment in this situation is an integration of botany, animal biology and agricultural economics and has to be considered as a whole.

1.2 LOCATION, GEOGRAPHY, POPULATION AND CLIMATE OF FIJI

The work described in this thesis was carried out in the Fiji archipelago which lies on the 180th meridian between latitude 12^{o} 28' S and 21^{o} 20' S in the south west Pacific (Figure 1.1). The total number of islands in the group is over 300 of which approximately 100 are permanently inhabited. Land area totals approximately 18,235 square kilometers, of which 10,388 square kilometres are accounted for by the main island, Viti Levu. Vanua Levu, the second largest island has an area of 5,535 square kilometres, thus the two major islands account for 87 percent of the total land area.

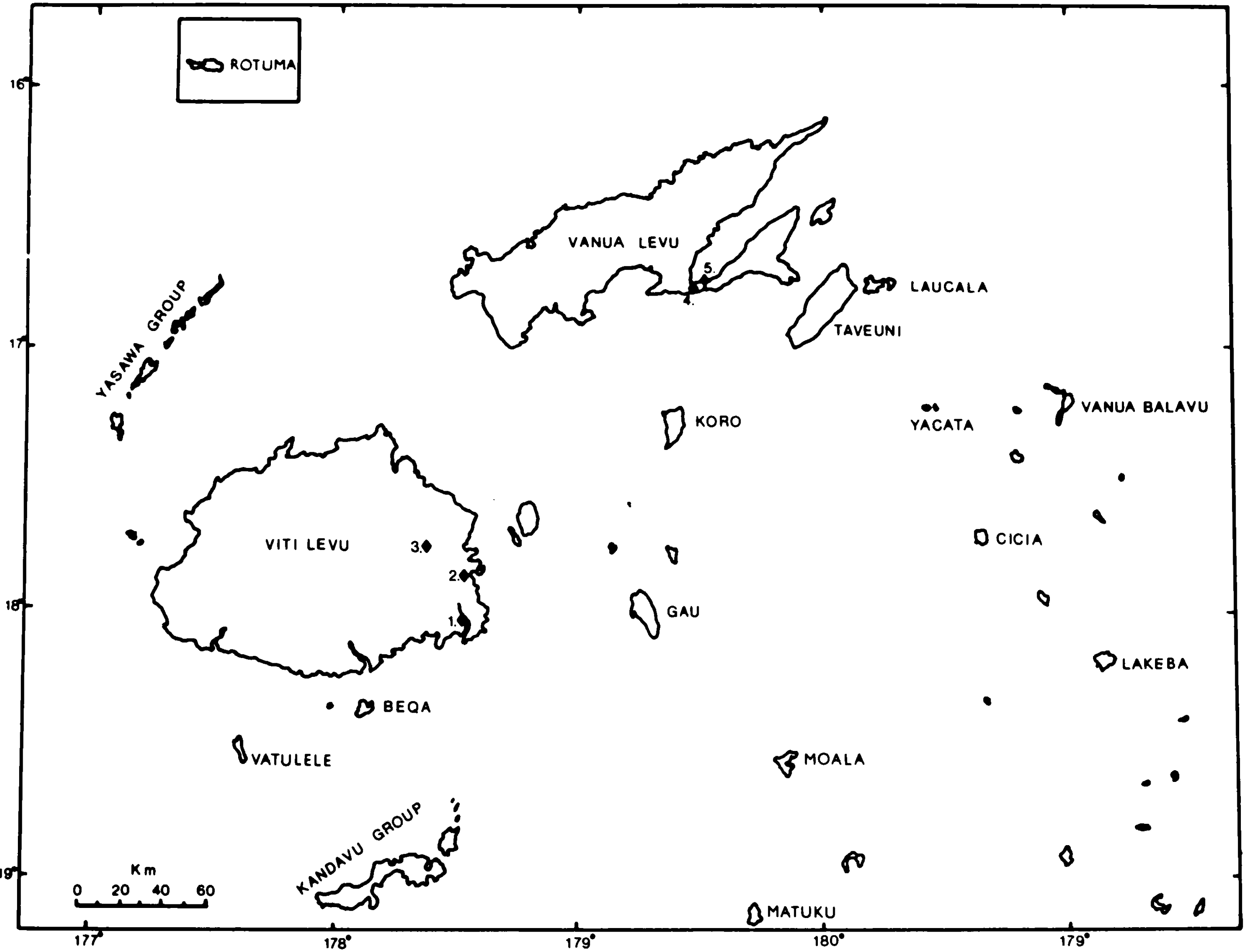
The capital and chief port of Fiji is Suva, in the south east of Viti Levu. Lautoka, the only other significant suburban area and the second port, is on the north west coast of Viti Levu as is the major international airport at Nadi.

The population of Fiji is 535,375 (1971 census), of which 51 percent are Indians that are mostly descendants of those taken to Fiji as indentured labourers. The remainder of the population consists of indigenous Fijians (43 percent) plus small numbers of Rotumans (1.2 percent), Part Europeans (1.8 percent), other Pacific Islanders (1.2 percent), Chinese (1.0 percent) and Europeans (0.8 percent).

FIGURE 1.1

FIJI ISLANDS, SHOWING THE LOCATION OF THE MAJOR STUDY AREAS

1. Koronivia Research Station
2. Namara Road Cocoa Plantation
3. Waimaro Cocoa Research Station
4. Wainigata Research Station
5. Salt Lake Coconut Plantation.



ROTUMA
VANUA LEVU
LAUCALA
TAVEUNI
YASAWA GROUP
KORO
YACATA
VANUA BALAVU
VITI LEVU
CICIA
GAU
LAKEBA
BEQA
VATULELE
MOALA
KANDAVU GROUP
MATUKU
Km
0 20 40 60
16°
17°
18°
19°
177°
178°
179°
180°
179°

Fiji's economy is based on agricultural produce, tourism and gold. Sugar is by far the most important agricultural export earning over F$30 million dollars (F$2,00 = ST£1.00 approx.) annually during the last few years, but the export of copra, copra products, bananas and ginger also contribute significantly to the national economy.

The Fijian archipelago lies within the zone of the south-east trade winds so that on the larger islands there is a marked difference in climate between the lowlands of the south-east side and those of the north-west, particularly when there is a high land mass separating the areas. The south-east trades are most constant during October and November (75 percent frequency) but they predominate until April or May when their direction changes more to the north-east. They are light to moderate moisture laden breezes during the day (lessening at night) which bring rain to the windward foothills and uplands, but are dry winds on the leeward coasts. Gale force winds from the south and east occasionally occur between May and August and are usually the result of anticyclones from the south. Such winds may damage tree crops but tropical hurricanes which infrequently sweep the Fiji group from the north between October and April can cause an immense amount of damage.

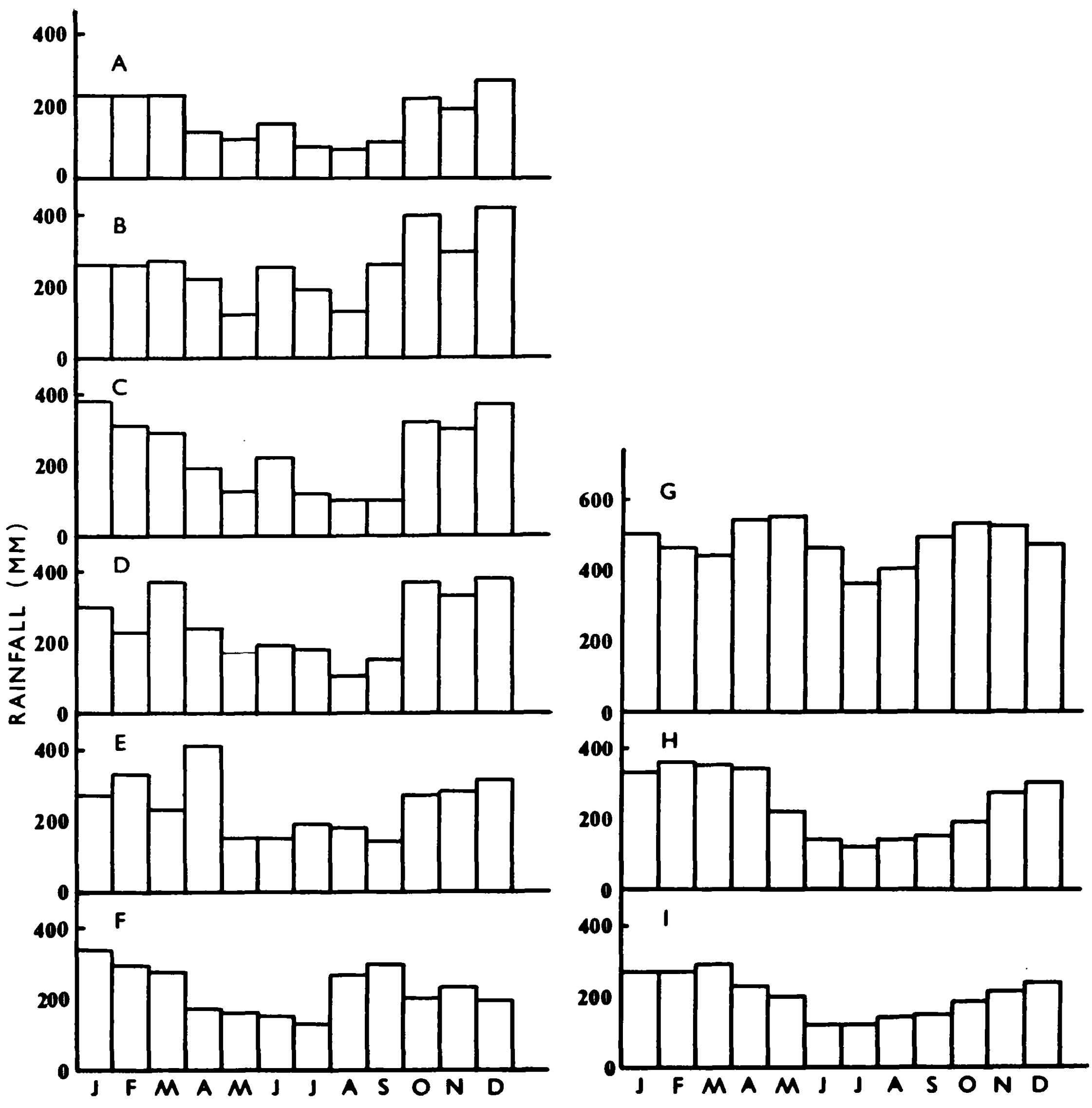
The windward side of large islands in Fiji are termed as being in the 'wet' zone (over 2500 mm per year) and leeward localities as the 'dry' zone (under 2000 mm per year), (Derrick, 1951), although part of the south-east coastal region of Vanua Levu and some of the smaller islands are exceptions in that they are not particularly wet (i.e. 2000 - 2500 mm per year). On many of the smaller high islands, such as Matuku Moala and Totoya, the climatic differences between windward and leeward sides are slight while on many of the low islands

FIGURE 1.2

MEAN MONTHLY RAINFALL FOR NINE SITES ON THE ISLANDS OF VITI LEVU (VT) VANUA LEVU (VA) AND TAVEUNI (T)

Sites A-F for years 1968-1972, sites G, H and I for 38, 41 and 54 years respectively.

A	=	VUNILANGI ESTATE	(VA)
B	=	VUNA	(T)
C	=	MATEI AIRPORT	(T)
D	=	NADURULOULOU COCOA STATION	(VT)
E	=	SAVU SAVU AIRPORT	(VA)
F	=	WAINIGATA RESEARCH STATION	(VA)
G	=	SALIA LEVU ESTATE	(T)
H	=	MUA ESTATE	(T)
I	=	VALECI	(VA)



RAINFALL (MM)
A
B
C
D
E
F
G
H
I
0
200
400
600
J F M A M J J A S O N D

such as Vatulele, Cicia and Lakeba there is little or no difference. Mean annual rainfall in the group ranges from over 5,100 mm on the uplands of Taveuni, Vanua Levu and Viti Levu to under 1,800 mm on the leeward coast of Viti Levu. July is almost always the driest month everywhere in Fiji, while the wettest varies from place to place in different years but is usually between November and April. The most stable weather in Fiji, that is least departures from average, is from June to August. Average monthly rainfall in selected coconut and cocoa growing areas, for the five years 1968 to 1972, is shown in Figure 1.2 along with records spanning 38 to 54 years for three sites.

Temperatures throughout the lowlands and foothills of Fiji are strongly influenced by the proximity of the surrounding ocean. The result is that the daily and seasonal range of temperature in lowland Fiji is comparatively small. The mean lowland temperature on the windward side is about 25°C and on the lee of the larger islands about 24.5°C. Mean monthly temperatures also vary little throughout the year, there being only a range of 6°C in the wet lowlands and 8°C in the dry lowlands. The diurnal range is also slight, the days being on average 6°C warmer than the nights.

Areas over 600 m altitude have a mean annual temperature of 20°C with temperatures as low as 7.5°C having been recorded (Twyford and Wright, 1965).

The coconut palm and the cocoa tree are both strictly tropical plants with all important producing areas of the world lying between latitudes 20°S and 20°N and below an altitude of 300 m. The location of Fiji's two main islands (Figure 1.1) makes it evident that the southern limits of these two crops are being approached. The coconut palm requires a mean monthly temperature of about 27°C with 20°C for any month being considered the lower limit (Fremond et al., 1966). An annual rainfall of 1500 mm is favoured with not less than 130 mm in any one month. The major coconut producing areas in Fiji have ample rainfall (Figure 1.2) although the lower limit is sometimes reached in June and July which causes (along with the lower temperatures) a marked seasonality in crop production (Figure 1.3).

The cocoa tree also favours a relatively high rainfall (at least 1150 mm per year) and for cultivation on a commercial scale minimum daily temperatures should not fall below 15°C while the average annual temperature should not be below 21°C (Erneholm, 1948). However cocoa can survive temperatures down to 10°C and tolerate a dry season provided the soil has an acceptable available water holding capacity.

1.3 FIJI RODENTS

Only four rodents are present in Fiji, three of which belong to the genus _Rattus_. This paucity of rodent species is not surprising in view of the isolated nature of the Fiji archipelago and it is of note that all four species have evidently spread in association with man.

Rattus exulans, the Polynesian rat, is the most widespread _Rattus_ species in Fiji and the Pacific (Figure 1.4). It originated in South East Asia, from where it probably spread with man to the East Indies, Philippines and the Pacific Islands (Tate, 1935). New Zealand, Easter Island and Hawaii represent the limits of the species' Pacific range. This species was first described as _Mus exulans_ (Peale, 1848) and was assigned various other names as it was discovered on other islands throughout the Pacific.

FIGURE 1.3

THE INFLUENCE OF RAINFALL ON THE SEASONAL DISTRIBUTION OF COCONUT PRODUCTION

(Site on Maravu Estate, Vanua Levu)

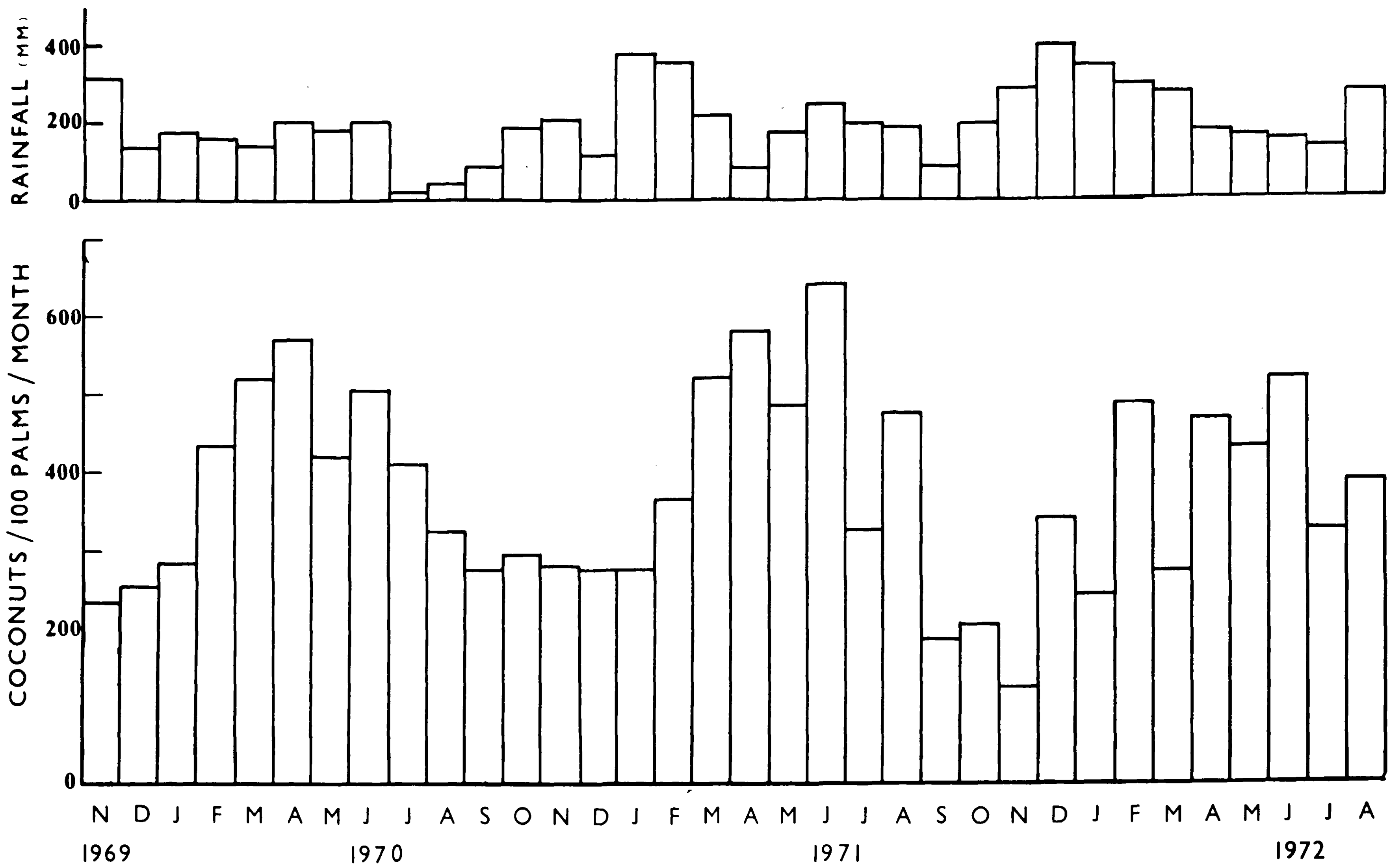

RAINFALL (MM)
400
200
0
COCONUTS / 100 PALMS / MONTH
600
400
200
0
N D J F M A M J J A S O N D J F M A M J J A S O N D J F M A M J J A
1969
1970
1971
1972

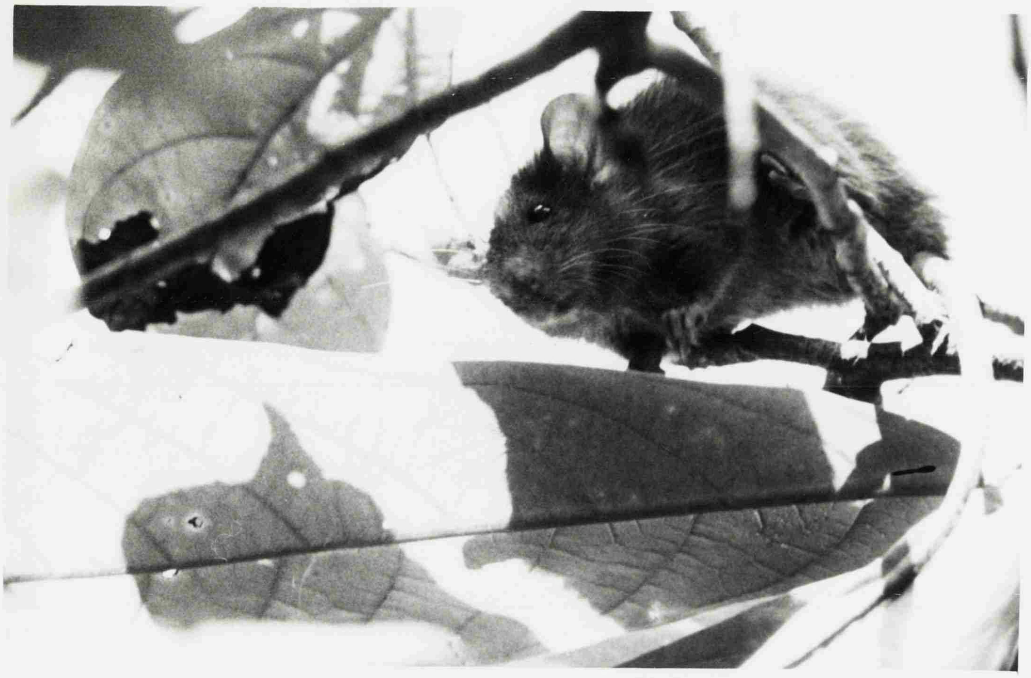
FIGURE 1.4

ADULT R. EXULANS MALE (POLYNESIA RAT)

FIGURE 1.5

ADULT R. RATTUS (SHIP OR ROOF RAT)

ADULT R. NORVEGICUS (NORWAY RAT)



Rattus rattus, the roof rat, is considered to be indigenous to most of India, Ceylon, Himalayan foothills, Burma, Southern China, Indo-China, Malay States, Sumatra, Java, Borneo, Celebes and the Philippines (Ellerman and Morrison -Scott, 1951). (Figure 1.5). It spread with commerce to most tropical and temperate regions of the world. The Roof rat is moderately widespread throughout the Pacific and Fiji representatives are probably derived from European stock which has spread in a westerly direction to the Americas and on into the Pacific. The European type stock is referable to as the subspecies Rattus rattus rattus (Johnson, 1962) and is now distinct from the many subspecies in South East Asia, some of which have invaded the Pacific in an easterly direction. A prominant characteristic of the subspecies R. r. rattus is the occurrence of three colour phases which have, for many years, been mistakenly designated as three separate subspecies - rattus for the generally slate-coloured member of the group, frugivorus for the brownish-gray type with white feet and underparts and alexandrinus for a phase that combined the gray back of frugivorus and the slaty underparts of rattus, the 'black' rat. The three colour phases occur in all large populations of the sub species, including Fiji, and although they do not intergrade phenotypically the rats of the different colour types interbreed freely, as has been pointed out repeatedly (reviewed by Tomich and Kami, 1966).

Rattus norvegicus, the Norway rat, is in view of the present distribution of wild races, a native of the Manchurian region of palearctic Asia. It arrived in Western Europe about 1750 along with commerce and has subsequently spread around the world by shipping. In its native land R. norvegicus is a stream bank inhabiting species that favours burrowing and swimming. It nests underground and is a relatively poor climber. Throughout the middle and high latitudes the species tends to thrive, particularly in urban areas, but in the tropics they survive in significant numbers only where the environment has been highly modified by man, as in coastal urban areas. Their spread into forest or cultivated areas in the tropics is very limited.

Mus musculus, the house mouse, is another Central Asian rodent that has spread with commerce and become cosmopolitan. Like *R. norvegicus* it is very successful in the temperature latitudes but also occurs widely in the tropics although in Fiji it appears to be present in relatively small numbers. Fiji house mouse populations are probably derived from the Western European sub species *Mus musculus domesticus* as defined by Schwarz and Schwarz (1943). This form is well established in the northern sections of North America, Australia and Hawaii.

1.4 BOTANY, AGRONOMY, AND ECONOMIC IMPORTANCE OF THE COCONUT PALM (COCOS NUCIFERA L.) AND THE COCOA TREE (THEOBROMA CACAO L.) IN FIJI

A large part of this study is devoted to rather unique tropical tree crops and it is therefore desirable that their morphology, biology and method of cultivation in Fiji be outlined.

1.4A COCOS NUCIFERA L.

I. Botany

The Fiji Tall palm (var. *typica*) is a monocotyledon with no cambium and therefore a stem that does not undergo secondary thickening. This results in a cylindrical trunk of 30-50 cm in diameter that reaches a height of 20-30 m. The stem, or trunk, is marked with leaf scars in the form of ring-like marks, and rises from a base of fine adventitious roots. An extensive root system is developed, primarily extending through the upper reaches of the soil. New roots are produced from the basal 0.7 m of the stem throughout the life of the plant.

The stem is topped by a crown of pinnate leaves which may individually reach a length of 5-6 m and weight of 10-15 kg. Each leaf consists of a strong pedicle extended to form the rachis or axis with the numerous leaflets inserted on it. Attachment is very firm with the leaf base extending around half the trunk circumference. The palm bears 25-30 leaves with the younger inner ones, surrounded by fibrous leaf sheaths, encircling the terminal bud. Under optimum conditions a new leaf unfurls every 25-30 days and has a life of 24-30 months (Purseglove, 1972).

Flower and fruit production normally commences 5-7 years after planting and full bearing in 10-12 years. Productive life then extends over a further 50-60 years. An inflorescence is produced in the axil of each leaf and carries flowers of both sexes. The whole inflorescence is initially enclosed in a sheath known as the 'spathe' which splits along one side to expose the flower bearing structures. Each inflorescence consists of a main axis, carrying up to 40 lateral branches on which the flowers are borne. (Figure 1.6). Up to 40 female flowers are located at the base of the branches and numerous male flowers are carried above, the latter numbering 200-300 per branch. Flowering takes place from the tip of the infloresence branch towards the base, with the male flowers opening and dispersing most of their pollen before the female flowers open. This method of flowering usually ensures cross-pollination, as it is not usual for two spathes to be open on a palm at the same time. Pollination is effected by wind and insects, although a percentage of the flowers are shed before this

FIGURE 1.3

COCONUT PALM CROWN FIJI TALL VARIETY WITH A NEWLY OPENED INFLORESCENCE BEARING TWO FEMALE FLOWERS occurs, and also in the one to two months following pollination. Such premature shedding is considered to keep the crop within the resource limits of the palm (Menon and Pandalan, 1957).

After fertilisation two carpels, of the three carpel ovary, abort and the remaining one develops into a fruit that reaches 25 cm in length and is termed a fibrous drupe. The exocarp of the young fruit is the thick fibrous mesocarp from which the 'coir' of commerce is obtained. Embedded in the mesocarp is the nut which consists of a very hard endocarp surrounding

the single se ... to the endocarp
and on the in ... elops.
A small embry ... the proximal
end of the nu ... roximately
five months a ... s full size
at six months ... ering, the
endosperm whi ... cm thick and
has a high oi ... ni phase
the nut cavit ... ning up to
five percent, ... oung nut this
fluid has an ... but this
decreases as ... pening process.

As a ne ... d nut development, from flowering to maturity, takes approximately 12 months there are usually 12-14 bunches on a palm at all times (Purseglove, 1972). A survey of 200 Fiji Tall palms during 1971 revealed an average of 13.7 bunches per palm. Fruit and leaf development are summarised in Figure 1.7.

11. Agronomy

A little over half of Fiji's coconut acerage is grown under plantation conditions (Table 1.1), that is, planted at regular intervals in relatively large blocks. Spacing varies, but a occurs, and also in the one to two months following pollination. Such premature shedding is considered to keep the crop within the resource limits of the palm (Menon and Pandalan, 1957).

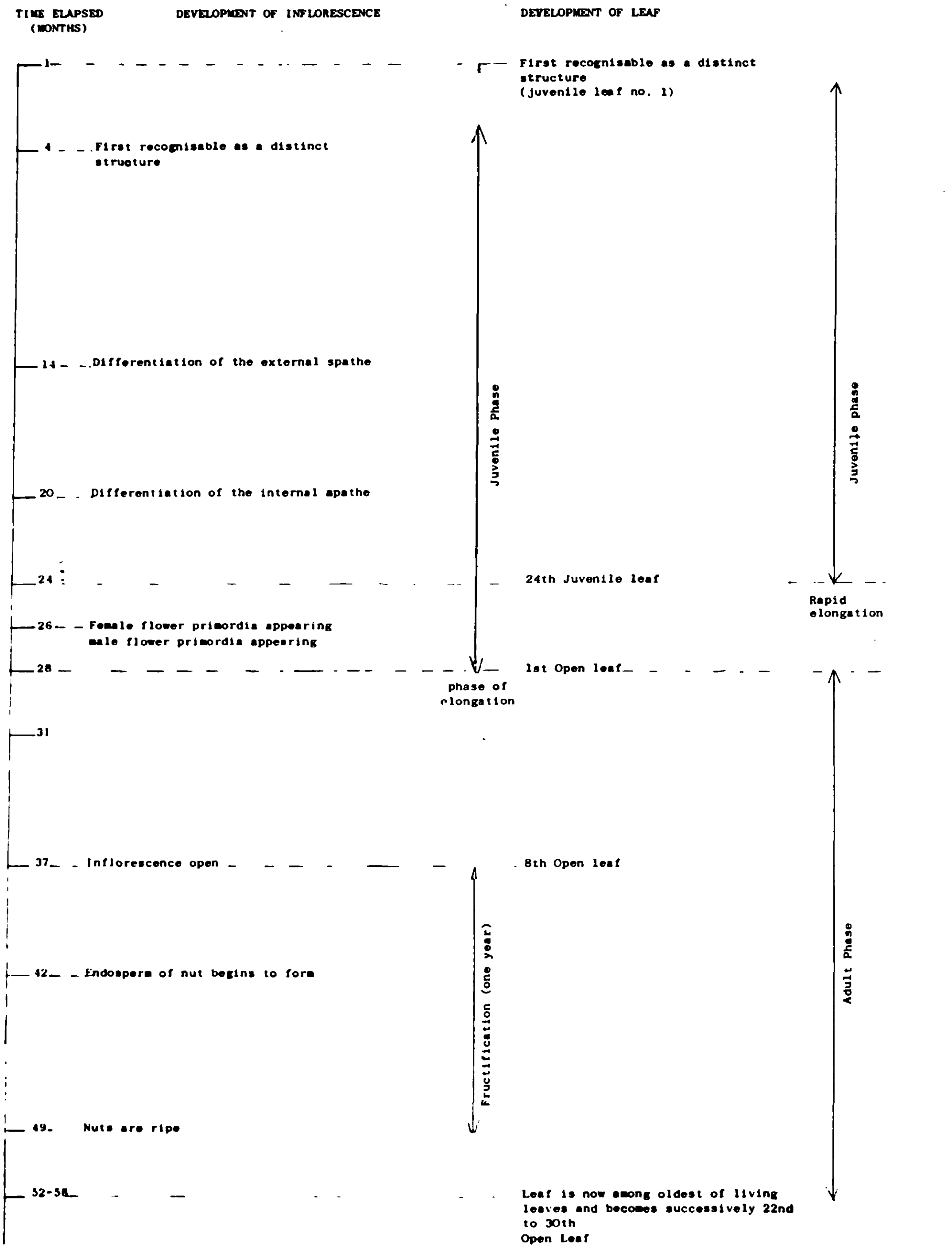
After fertilisation two carpels, of the three carpel ovary, abort and the remaining one develops into a fruit that reaches 25 cm in length and is termed a fibrous drupe. The exocarp of the young fruit is the thick fibrous mesocarp from which the 'coir' of commerce is obtained. Embedded in the mesocarp is the nut which consists of a very hard endocarp surrounding the single seed. The seed testa adheres closely to the endocarp and on the inner surface of this the endosperm develops. A small embryo is located within the endosperm at the proximal end of the nut. Endosperm development begins approximately five months after flowering and the coconut reaches full size at six months. At maturity, 12 months after flowering, the endosperm which is termed copra when dried is 1-2 cm thick and has a high oil content. Throughout the development phase the nut cavity is filled with coconut water containing up to five percent sugars plus growth hormones. In a young nut this fluid has an osmotic pressure of five atmospheres but this decreases as the sugars are absorbed during the ripening process.

As a new inflorescence emerges each month and nut development, from flowering to maturity, takes approximately 12 months there are usually 12-14 bunches on a palm at all times (Purseglove, 1972). A survey of 200 Fiji Tall palms during 1971 revealed an average of 13.7 bunches per palm. Fruit and leaf development are summarised in Figure 1.7.

II. Agronomy

A little over half of Fiji's coconut acerage is grown under plantation conditions (Table 1.1), that is, planted at regular intervals in relatively large blocks. Spacing varies, but a diagonal layout of 8.5 m by 9.0 m is common and produces a density

Figure 1.7 CHRONOLOGICAL SCHEME OF THE DEVELOPMENT OF A LEAF AND OF ITS CORRESPONDING INFLORESCENCE



* Note : About one year passes between the differentiation of the female flowers and the opining of the spathe, and another year after this before the nuts are ripe.

(After Fremond et al. (1966).)

Table 1.1 THE AREA UNDER COCONUT CULTIVATION, COPRA PRODUCED AND COPRA VALUE 1875-1968

Estimated Areas (hectares)			Copra Production and Value			
Date	Plantations	Groves	Period	Known production, tonnes per year (period means)	Average annual value of copra and copra products exported. (F$)	Value of cropra and copra products as a percentage of domestic exports.
1875	506		1870-1889	4,190	98,400	21.5
1890	7,500		1890-1899	6,030	112,357	12.9
1900	9,300		1900-1909	11,100	281,013	20.6
1910	12,100		1910-1919	14,800	620,321	20.1
1920	20,200		1920-1927	21,900	740,220	27.1
1928	19,400	33,200	1928-1939	22,920	742,456	17.8
1950	29,100	36,800	1940-1949	24,300	1,408,675	23.5
1962	68,000		1950-1959	34,750	4,875,406	25.9
1968	76,000		1960-1969	32,200	4,669,164	25.3

Note: All pre 1962 figures are taken from McPaul (1963) while post 1962 data is from Leather (1972).

141 @ 9m, 181 @ 8m.

of 160 palms per hectare. The remainder of the palm area is in the form of irregular groves, at densities of up to 250 palms per hectare.

The standard of plantation management varies considerably with the better properties making extensive use of herbicides and tractor powered slashers for weed control in addition to mechanising coconut collection and copra drying. Cattle are frequently grazed under coconuts sometimes with the prime aim of controlling undergrowth, but more frequently as an integration of beef and copra production (Figure 1.8). Poorly managed plantations or groves are frequently overgrown and often contain many young selfsown palms that are the result of infrequent or haphazard nut collection (Figure 1.9).

In general coconut production in Fiji could be described as an extractive industry, for fertlisers are seldom used. This is considered to limit the nut production of younger palms but probably has little effect on older palms, that is those over 60 years (Leather, 1972). The age structure of Fiji's palm population has caused considerable concern over the last 10 years. McPaul (1963) estimated that one third of Fiji's 68,000 ha of palms were over 60 years old. Although extensive re-planting during the 1960's reduced this percentage, large areas of old palms still need replacing.

Nut collection on the larger plantations is at approximately monthly intervals with collection being confined to nuts that have fallen; none are harvested from the palm crown as is common practice in countries such as India and Ceylon. The nuts are mostly cut in the plantation and the nut kernel transported to a central drier that is fired by wood, coconut husks or occasionally oil.

III. Economic importance

The cultivation of the coconut palm in Fiji has been a

FIGURE 1.8

A MATURE STAND OF FIJI TALL PALMS AT VUNILAGI ESTATE VANUA LEVU ILLUSTRATING THE INTEGRATION OF CATTLE AND COCONUT FARMING

FIGURE 1.9

A PLANTATION WITH EXCESSIVE UNDERGROWTH, NABAKA PLOT, VANUA LEVU (Note standing man lower centre).

significant agricultural endeavour since the early 1880's and from 1882 until the present copra has been Fiji's second agricultural export, surpassed only by sugar. However for decades prior to extensive organised cultivation coconuts had been an important article of trade in addition to being a source of food and building material for the indigenous people, the latter features are still the case today.

Coconut cultivation is a relatively simple form of agriculture in comparison to many other tree crops, but during the last 90 years the Fiji coconut industry has faced a number of major problems that have been mostly beyond the control of the farmers. Low copra prices, hurricanes, labour problems, insect pests and droughts have all influenced production. Nevertheless the period has seen a general increase in coconut production with the average value of the crop, in terms of total export earnings, remaining at approximately 20 percent for the last two decades (Table 1.1.)

During the 1960's the export of coconut products contributed F$4-5 million dollars annually to the national economy and provided the major source of income for many of Fiji's outer island communities. The relative importance of coconut production to sectors of the farming community in Fiji is evident when the distribution of copra is examined in terms of geography and the racial composition of the coconut farmers. The south coast of Vanua Levu, Taveuni and the Lau Islands are the major coconut growing areas in Fiji and produce 75 percent of total production (Table 1.2). Other producing areas are the islands of Lomaiviti, Kadavu, Vatulele, Yasawa's, parts of Viti Levu and Rotuma.

In the coconut growing regions most coastal embayments and areas of flat land have at least a fringe of palms (Figure 1.10). and on freehold or leasehold land plantings extend well inland

FIGURE 1.10

TYPICAL STRIP OF PALMS ALONG THE COAST OF ONE OF FIJI'S SMALLER ISLANDS (KIOA)

FIGURE 1.11

TYPICAL EXPANSE OF PALMS AT AN INLAND SITE ON VANUA LEVU (SALT LAKE)

Table 1.2 DISTRIBUTION OF COPRA PRODUCTION IN FIJI

Region	Production (tonnes)	Percentage of total production
South coast of Vanua Levu including Buca Bay, Natewa Bay, Udu Point and Rabi Island	8,850	22.5
Taveuni	11,800	30.0
Lau Islands	8,850	22.5
Lomaiviti, Kadavu and Vatulele Islands	4,820	12.5
Yasawa Islands and Viti Levu	1,970	5.0
Rotuma Island	2,950	7.5

Note: This table is based on the records of Island Industries Ltd. for the period 1957 to 1962 as cited by McPaul (1963).

(Figure 1.11) though they are rarely grown over an altitude of 300 m, because temperatures frequently drop to levels that retard growth.

Non physical factors have played a significant part in governing the distribution of coconut growing in Fiji. Ward (1965) considers that the present distribution of Fijian palm groves owes much to the distribution of the population, while that of estates is directly related to the pattern of land tenure and lack of alternative marketable crops during the late nineteenth and early twentieth centuries. In areas where sugar mills were established or bananas could be grown for export, such quick maturing crops were preferred. Transport difficulties have always restricted the range of commercial crops that can be grown on the outer islands , so copra which can be stored for some time, has been and will continue to be important.

The coconut growing areas are mostly populated by Fijians although other relatively minor ethinic groups farm a similar area to the Fijian population (Table 1.3).

Table 1.3 LAND UNDER COCONUTS FARMED BY MAJOR RACIAL GROUPS

Group	Area (hectares)
Fijian	34,000
European and part European	30,600
Indian	2,020
Chinese and others	1,215

Note: Data from Ward (1965).

The coconut palm provides, in many instances, the major source of income for Fijian farmers who are basically following a pattern of subsistence agriculture. While other crops such as Yaqona (Piper methysticum Forst.) and Dale (Colocasia esculenta (L) Schett var esculenta) also provide cash incomes they depend on local markets which can rapidly become oversupplied. In contrast, copra is sold on the world markets where prices certainly fluctuate, but there is always a demand which will probably increase as world edible oil requirements rise.

It is evident that the coconut palm contributes significantly to the Fijian national economy while constituting the major source of cash income and an important source of building materials for a large section of the Fijian population in outer island communities.

1.4B THEOBROMA CACAO L.

I. Botany

In its natural habitat Theobroma cacao is a small tree in the lowest storey of the evergreen rain forest of South America. Its centre of origin is thought to be on the lower eastern slopes of the Andes (Cheeseman, 1944, cited by Purseglove, 1968) from where it has spread throughout Central Amazonia and north to southern Mexico. These populations developed into two recognised subspecies, the Central American Crillo and the Amazonian Forastero or Amelanado which were geographically separated by the Panama isthmus (Cuatrecasa, 1964, cited by Purseglove, 1968). The two subspecies and various forms of them interbreed to give fertile F_1 hybrids, many of which are known as Trinitario cocoas. These hybrids are widely grown today, and were the principal type grown in Fiji before the introduction of the subspecies Amelanado.

The cultivated cocoa tree is 4.5-7.5 m in height with a short main trunk of 1.0-1.5 m and a strong tap root. At the top of the main trunk are borne a number of lateral branches known as the 'fan' and on these fan branches leaves are carried in two ranks arranged alternately along the branch (Figure 1.12). As the fan is developed a new leading shoot, known as a 'chupon' is produced from below the fan and along the chupon the leaves are arranged spirally. This dimorphic branching is repeated several times to form a mature tree but under commercial cultivation this growth form is modified by pruning. Growth proceeds by a series of flushes, the young leaves being produced in rapid succession by a burst of activity at the terminal buds. At maturity these leaves are ovate and reach a length of 30 cm. There are usually two to four flushes per year but only one period of marked leaf fall (Purseglove, 1968).

The growth rate of cocoa largely depends on the environmental conditions, with the crop normally being cultivated under shade trees. Young cocoa trees are particularly susceptible to excessive light intensities and vegetative growth is most satisfactory when an almost complete canopy is provided.

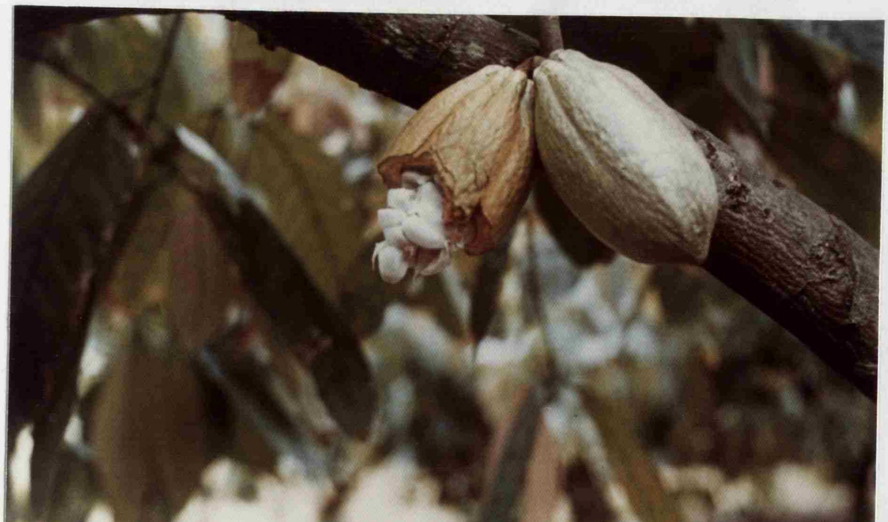
A feature of cocoa is the way the flowers are carried in clusters on the main trunk or older branches. They are bisexual

FIGURE 1.12

COCOA TREE (SUBSPECIES AMELANADO) SHOWING THE LOCATION OF MATURE FRUIT

FIGURE 1.13

RIPE COCOA POD (SUBSPECIES AMELANADO) OPENED TO SHOW THE BEANS ENCASED IN THE WHITE PULP



and arise from small cushions at points which represent the axil of former leaves. There is a considerable wastage of flowers due to shedding either before or after pollination and it is estimated that only five percent of the flowers produced ever develop into mature fruit (Urquhart, 1955). Cocoa trees start bearing in the fourth or fifth year and under ideal conditions, not often achieved in Fiji, will continue for 50 or more years.

The cocoa fruit is botanically a drupe but is commonly called a pod. It takes six months to mature, changing from green or purple to yellow in colour depending on subspecies. A considerable number of young fruit are shed prematurely, frequently as a result of physiological or nutritional disturbances. Each mature fruit, which is borne on a short stalk attached directly to the stem is 5-10 cm in diameter and up to 30 cm in length. The 30-40 seeds which develop within each fruit are embedded in a mass of pink or white pulp formed from the outer layers of the testa (Figure 1.13). A thick woody pericarp surrounds the seeds and pulp and constitutes about 25 percent of the weight of the mature fruit.

While some flowers are produced throughout the year in Fiji there is a marked lull during the middle of the year, probably due to the lower temperatures, which results in little or no production during December or January.

II. Agronomy

In contrast to coconut cultivation very little of Fiji's cocoa is grown on large plantations. Most is confined to small holdings of less than two hectares which seldom produce more than 10,000 pods per year.

Tree density varies but row and inter-row spacings of 3.0 to 4.5 m are common, giving a density of 450 to 1050 per hectare. Most farms have been established in the last 20 years even though there were earlier attempts to cultivate the crop on a large scale. However the total area under cocoa cultivation today is small (probably less than 700 ha) but increasing as the crop becomes more popular with farmers in areas where soil and rainfall are suitable.

As outlined above, the cocoa tree favours a shaded environment. In Fiji this has largely been achieved by partially clearing indigenous bush or forest, although in some areas fast growing shade trees have been planted or the shade of mature coconuts plantings have been used. The presence of shade trees combined with the almost complete canopy formed by mature cocoa largely prevents the growth of other vegetation; that which does develop is removed on well managed properties by hand weeding or herbicide sprays. Fertilisers are seldom used for it has not yet been established in Fiji that cocoa responds economically to fertilisers (Fiji Dept. Agric. Annual Report, 1971).

The harvest of mature pods is usually carried out weekly as this reduces the level of both blackpod and rat damage (Section 5.4) although ripe pods can remain on the tree for at least four weeks with little deterioration. Following collection pods are opened, the beans removed, and then fermented at 48-49°C for 4-7 days. Fermentation is followed by hot air drying, both processes usually carried out at centralised Co-operative or Government fermentaries.

III. Economic importance

Cocoa was first planted in Fiji in 1880 and by 1900 a small cocoa industry had built up on the S.E. coast of Vanua Levu and on the Island of Taveuni. The industry did not expand because of the prevailing high prices of copra, damage to ripe pods supposedly caused by Flying Foxes (*Pteropus sp.*) and Rose Beetle (*Adoretus versutus*) attack on young trees (Twyford and

Wright, 1965). After a severe hurricane damaged many of the plantations in 1912, cocoa growing was abandoned.

In 1952 a major attempt was made by the Agriculture Department to redevelop a cocoa industry in Fiji and by 1965 about 500 ha (Vernon, pers. comm) had been established even though yields were being reduced by a disease that was later identified as cocoa canker Botryodiplodia theobromae Pat. (Firman and Vernon, 1970). The trinitario variety then being grown was particularly susceptible to this disease.

By the late 1960's the better yields of Amelanado cocoa, a more canker resistant variety, coupled with the rising world prices renewed interest in the crop. Farmers were encouraged to expand their plantings and did so because well maintained properties were yielding up to 1900 kg per hectare per year; worth about F$250.0 to the farmer (Dept. Agric. Annual Report, 1970). It is the relatively high value of the crop and the ease with which it can be established (no expensive agricultural machinery is required), that makes cocoa an important cash crop for subsistence farmers who have little capital and usually only hand tools.

Despite the increase in cocoa growing, the crop only makes a small contribution to the national economy (Table 1.4) but production is expected to rise as more farmers realise the potential of the crop.

Table 1.4 COCOA PRODUCTION AND VALUE

Year	Pods produced	Tonnes of cocoa beans	Approx. export value (F$)
1969	1,903,268	58.5	17,500
1970	1,779,455	57.5	17,250
1971	1,983,550	66.5	20,000
1972	-	77.0	-

Data from Dept. of Agric. Annual Reports for Years 1970 to 1972.

POPULATION ECOLOGY OF RATTUS SPECIES IN COCONUT AND COCOA PLANTATIONS

Chapter 2

2.1 REVIEW

Rattus exulans is the most widespread and numerous Rattus species in the Pacific being present on most inhabited islands. R. rattus and R. norvegious have a restricted distribution, in particular the latter species for, as discussed in Section 1.3, they are relatively new arrivals to the Pacific basin. R. exulans and R. rattus are the most important Rattus species in the region as they cause considerable damage to coconuts (Chapter 3), sugar-cane, rice and cocoa (Chapter 5). In some areas, both species are also important vectors of the typhus carrying mite and the plague flea (Audy and Harrison, 1951; Elbel and Thaineua, 1957).

Literature pertaining to the general ecology of R. exulans has been fully reviewed by Williams (1973) while that relating to R. rattus and R. norvegicus ecology within the Pacific area has been reviewed by Strecker et al. (1962). Therefore only major aspects are discussed here.

2.1A HABITATS

In Hawaii all three Rattus species have been found occupying gulches adjacent to canefields (Bianchi, 1961 and Kami, 1966). R. exulans and R. rattus were relatively abundant and in approximately equal numbers while R. norvegicus were present in only small numbers. Kami (1966), working in Hawaiian canefields, gulches and grasslands found R. exulans favoured dry gulches and grasslands and was more abundant that R. rattus in these habitats. In contrast, R. rattus were present in greater numbers than R. exulans in canefields. R. norvegicus were relatively rare in all habitats throughout the 10 year study.

On Ponape, in the Caroline Islands, Strecker and Jackson (1962a) found R. exulans to be the most abundant species in the three habitats studied (rainforest, grassland and coconut plantations),with the highest densities occurring in the coconut plantations.

Baker (1946) found R. rattus to be more widespread than R. exulans on Guam, occupying grass and bush uplands in volcanic areas, rocky coral jungles, coconut groves, fallow fields and villages. R. exulans appeared to prefer dry grassland and coconut areas and was absent from the jungle and villages.

In the Tongan Islands all three species were trapped in coconut groves, vegetable gardens and areas of light bush (Pierce, 1971; Whelan and Whelan, 1971) but R. exulans and R. rattus were more widespread and prevalent that R. norvegicus, particularly in coconut groves. More R. rattus were caught in the crowns of coconut palms (80 percent of all captures) than either of the other two species, suggesting that the species climbed more freely than the other two.

It appears, at least within the Pacific area, that R. exulans favours areas with good ground cover on relatively dry, or at least well-drained soils. In contrast R. rattus is found in greater numbers in the damp environment of cane-fields, in the arboreal sector of coconut plantations and within jungle areas.

2.1B MOVEMENT

Many measures of small mammal movement have been proposed, some attempting to measure the area occupied by an animal, such as Harrison's (1958) "standard range" which is expressed as the diameter of a circle in which 68 percent of the recaptures occur. Other methods have concentrated on linear distances between successive captures rather than on distances moved from the point of original capture as in areal measures. The former seems a more realistic approach as Stumf and Mohr (1962) have shown that the true home ranges of a variety of mammals tend to be linear. Verts (1963), using Stumf and Mohr's technique, found that the home ranges of opossums in Illinois were about 2.9 times as long as wide while Sanderson and Sanderson (1964) showed that the home range of radio tracked rats in Malaya were linear even in a field situation where there were no obvious linear aspects.

Several estimates of Rattus movements have been made in the Pacific region, most using a linear measure and all based on a grid of traps. On Guam, Baker (1946) found that 77.5 percent of R. exulans and 71.6 percent of R. rattus were within 22.8 m of the previous capture. In Hawaiian canefields and in adjacent gulches, Kartman and Lonergan (1955) found 85.0 percent of R. exulans and 69.0 percent of R. rattus movements from the point of original capture were less than 15.0 m, while 90.0 percent and 80.0 percent respectively were within 30.5 m. In contrast, Spencer and Davis (1950), working on an overgrown Hawaiian mountain slope found that only 53.0 percent of R. exulans recaptures occurred within 30.5 m of the point of previous capture and 81.0 percent within 61.0 m. Movements by R. rattus were also greater at this site, 77.0 percent of the distances moved by females and 66.0 percent by males were less than 61.0 m. Jackson and Strecker (1962) found that 70.0 percent of R. exulans successive recaptures on Ponape were within 18.2 m of each other, results very similar to those obtained by Baker (1946). Ponapean R. rattus moved greater distances than

R. exulans, but 60.0 percent of the movements by males and 70.0 percent of those by females were within 37.0 m.

Tomich (1970) has also provided a considerable amount of information on the movements of R. exulans and R. rattus in canefields and adjacent gulch areas in Hawaii. He utilised two linear measures, the first proposed by Stickel (1954) and the second by Brant (1962). Both methods have been used to express the results of present movement studies in Fiji coconut and cocoa plantations, and details are therefore discussed in Section 2.4B.

2.1C INTERSPECIFIC COMPETITION

The amount of competition between tropical Rattus species has not been well assessed. Harrison (1957) provided some evidence of habitat separation, between species sharing a common vegetation type in Malaya, by comparing differences in the level of infestation by trombiculid mites. This approach provided an index of where the host animals had been foraging. Large numbers of one species of mite (Trombicula akamuski) were found on two sub-species of R. rattus but comparatively few were found on R. exulans even though the species occupied the same macrohabitat. Larvae of the mite T. akamuski congregated on the soil surface which suggested that R. exulans did not have close contact with the ground. However dietary differences could have accounted for this apparent separation of species as R. rattus sub-species ate a large number of insects, possibly gathered by disturbing leaf litter etc., while R. exulans ate mostly vegetable matter (Harrison, 1954). Host specificity was unlikely to have accounted for this mite distribution for the species involved were free-living and the larval stages parasitize any available mammal or bird (Hughes, 1959).

A vertical separation of species has been reported on several Pacific Islands, particularly in coconut groves (Baker, 1946; Barbehenn and Strecker, 1962 and Fall et al., 1971). R. rattus was considered to occupy the palm crowns, at least at night, and thereby exclude R. exulans.

Strecker and Jackson (1962b) demonstrated, using a cage 3.0 m x 3.0 m that R. rattus and R. exulans could live together in a small area provided food and separate niches were available. However, recent work by Barnett (1964) indicated that there were many factors that could affect such an association. He found that if male R. rattus and R. norvegicus were added simultaneously to an enclosure, they lived together without conflict, but if males were introduced at 10 minute intervals the first-comers established territorial rights within the cage which they defended against later entrants. Such behaviour could clearly affect the distribution of Rattus species in coconut plantations where palm crowns comprise one of the many niches in the habitat.

2.1D. REPRODUCTION

The term reproduction is usually used to cover all the processes leading up to the addition of young animals to the population. There are clearly many stages from the release of ova to the weaning of young but three of the most important aspects are the number and duration of breeding seasons, the proportion of the population that breeds and the number of young they produce, since these govern the extent of recruitment into a population during any year.

Jackson (1962) found that R. rattus on Ponape bred throughout the year, while Harrison (1951 and 1952) recorded a bi-monthly breeding rhythm and attempted to relate it to the lunar cycle. Nicholson and Warner (1953) found breeding throughout the year excepting the dry season during May, June and July in New Caledonia.

R. exulans was found to have a pronounced annual breeding peak during July - September on Ponape (Jackson 1962) but Harrison (1952) found no marked breeding season in Malaya. Watson (1956) indicated a possible breeding peak in March in New Zealand (late summer) while in New Caledonia Nicholson and Warner (1953) found a major breeding peak in November (spring) and a second one in April (early autumn).

The percentage of R. rattus females pregnant on the island on Ponape and in Malaya were similar (Harrison, 1951; Jackson, 1962), 15.7 percent and 13.8 percent respectively. However the number of embryos per female was lower on Ponape (3.8) than in Malaya (5.7) a feature also common to R. exulans populations. On Ponape Jackson (1962) found the average number of embryos per R. exulans female was 2.5 while on Majuro it was 3.0. In contrast, Harrison (1951) recorded a figure of 4.5 in Malaya. Jackson (1962) considered that the apparently elevated reproduction rates in Malaya were the result of a higher probability of dying, possibly because of higher levels of predation.

The reproductive rates of R. rattus and R. exulans on Ponape (the most detailed study of a Pacific Island Rattus population) were strikingly different from those in other populations studied in Malaya and elsewhere (Jackson, 1962). The prevalence of pregnancy and average litter size were as much as 50 percent lower than in other regions. Breeding continued throughout the year in both species but R. rattus breeding peaks seemed to correlate with the drier seasons; no such correlation was evident in R. exulans breeding patterns.

2.1E DENSITIES

Determining the absolute numbers of rodents within a particular area has proved difficult in many parts of the world and there are few estimates for Rattus populations within the Pacific area.

In a Guam habitat consisting of modified forest, grassland and coconut groves, Baker (1946) found R. rattus populations ranged from 10.0 to 29.0 per hectare while R. exulans ranged from 6.0 to 21.0 per hectare. Strecker (1962) recorded higher densities of R. exulans (44.5 and 74.3 per hectare respectively) in a grassland and a coconut area on Ponape, but captured insufficient R. rattus to enable population numbers to be estimated.

Wodzicki (1968) found R. exulans to be the only rat present in the Tokelau Islands and estimated that densities ranged from 42.0 to 183.0 per hectare in coconut groves. However these estimates were derived from very small grids and it is unlikely that the assumptions underlying the estimates were met.

In Hawaii the highest populations of R. exulans and R. rattus were found in dry gulches (Tomich, 1970). R. exulans and R. rattus numbers ranged from 2.5 to 32.2 and 2.5 to 24.6 per hectare respectively, with an annual peak of abundance occurring in the early winter (November - December).

With one exception (Wodzicki, 1968) the population estimates discussed have not included confidence limits, nevertheless they indicate that numbers vary considerably between habitats and throughout the year with R. rattus numbers tending to be lower than R. exulans although there are few estimates for this species.

2.1F SURVIVAL

Little appears to be known about the actual causes of death among wild rodents and few tropical studies have recorded the presence of dead or dying rats (Harrison, 1956; Jackson and Barbehenn, 1962).

Despite uncertainties as to the actual causes of death, estimates of survival have been made. By approximating the chronological age of Malayan rats using weight relationships, Harrison (1956) determined monthly survival rates of 0.80 and 0.83 for male and female R. rattus and 0.85 for the combined sexes of R. exulans. The mean length of life (calculated as 1/log s, where s = constant survival rate per month) was calculated as 4.4 and 5.2 months for male and female R. rattus respectively, and 6.3 months for R. exulans.

R. exulans had an annual probability of disappearance (approximate annual survival on Ponape of 0.60 (Jackson and Barbehenn, 1962) which was much higher than the survival rate calculated by Harrison (1956) for R. rattus (males, 0.07; females 0.10) and R. exulans (0.14) in Malaya. Jackson and Barbehenn (1962) thought this marked difference could have been due to a lower level of predation on Ponape.

Estimates of mortality, when the population was known or estimated, have been calculated for rural temperate R. norvegicus populations (Davis, 1953). The annual probability of survival was approximately 5.0 percent, which is in agreement with Harrison's figures for R. rattus in Malaya (7-10 percent).

This limited review suggests that few individuals in a Rattus population live longer than 12 months and that less than 50.0 percent survive for more than six months.

2.1G NUTRITION

Fall et al. (1971) carried out the most recent and detailed study of R. rattus and R. exulans diets on a Pacific Island. Using micro-techniques they calculated the frequency of occurrence and percentage of materials present in the stomachs of 85 R. rattus and 83 R. exulans from Eniwetok Atoll. Plant foods were predominant in the diets of both rat species with two shrubs (Scaevola and Tournefortia) accounting for 80 percent of R. exulans and 66 percent of R. rattus diet on a weight basis. The high prevalence of both shrub species reflected their greater abundance in virtually all habitats. Insect parts constituted a small fraction of the stomach contents on a weight basis, however they occurred in 33 percent of R. rattus stomachs but less than 10 percent of the R. exulans stomachs.

Little other quantitative information has been collected on the food habits of Rattus sp. on Pacific Islands; most analyses have been based on gross examination of stomach contents. Baker (1946) found about 80 percent plant materials and 20 percent insect remains in six stomachs of R. exulans on Guam. Marshall (1955) examined 11 stomachs of R. exulans from Arno Atoll and found the remains of coconut flowers, coconut kernel and fruits of a herbaceous plant, Triumfetta. Strecker and Jackson (1962a) reported that the stomach contents of 25 R. rattus from grassland habitats on Ponape (Caroline Islands) consisted of 45 percent plant material (estimated volume). Seven of the stomachs contained arthropod remains. Stomachs from 46 R. exulans from several habitats on Ponape and Majuro Atoll had 94 percent plant material (estimated volume); 19 of the stomachs had arthropod remains.

Harrison (1954) noted food habits of rodents in Borneo. Stomachs of R. exulans trapped in grasslands contained mostly vegetable matter with less than 20 percent of contents being insect remains. Two grassland sub-species of R. rattus had a more varied diet. Stomach remains indicated that the diet was about equally divided between insects, mostly termites, and vegetable matter.

Kami (1966) analysed the stomachs of a large number of rats from various habitats on the island of Hawaii. Sugar cane was the predominant food of R. exulans trapped in the cane field and in the bordering gulches. In the latter habitat, various fruits, nuts, berries and insects were also important items in the stomach, varying with the season. The diet of R. rattus in canefields was similar to that of R. exulans with sugar cane being the most frequent food item.

It is apparent that plant foods predominated in the diets of both species, with R. rattus tending to eat a wider range of foods, including a higher proportion of insects or other animal material.

2.2 OBJECTIVES OF THE ECOLOGY STUDY

Only two of the early investigations of rat damage in Fiji mentioned the species involved (Yelf, 1964 and Marshall, 1965) and no attempts have been made to investigate their population biology in relation to coconuts or to any other crops. It was therefore considered essential to investigate major aspects of the population biology of the three Rattus species, as well as their relative importance as a pest in order to gain a better understanding of them in the tropical Fijian habitat.

The aims of this section of the survey included determination of the distribution of the three species, their population densities, reproductive characteristics, age structure, survival rates and movements. Such an investigation of a rodent population had to be approached with a variety of techniques and methods. Aspects, such as reproduction and age structure, can best be understood by measuring and examining representative samples of animals removed from a population, by such methods as break-back trapping. In contrast, other methods of population dynamics, e.g. population levels and movement, need to be approached by an extended study which has minimal impact on the overall activities of the population. This can be achieved by mark-recapture programmes which enable a percentage of marked animals to be maintained within a population so that their movements and survival can be monitored. To achieve these aims two coconut and three cocoa sites were selected for long-term studies while numerous other locations were trapped for a few consecutive nights.

2.2A STUDY AREAS AND BASIS FOR SELECTION

I. General survey

To determine the geographical distribution of the three species in Fiji within cocoa and coconut plantations, lines of break-back traps were set in as many coconut and cocoa growing areas as possible. Sites on the main islands (Viti Levu, Vanua Levu and Taveuni) were selected to cover a range of plantation types and habitats. On outer islands the trapping sites were governed by the areas that could be visited by chartered boat and despite this limitation these areas were generally representative.

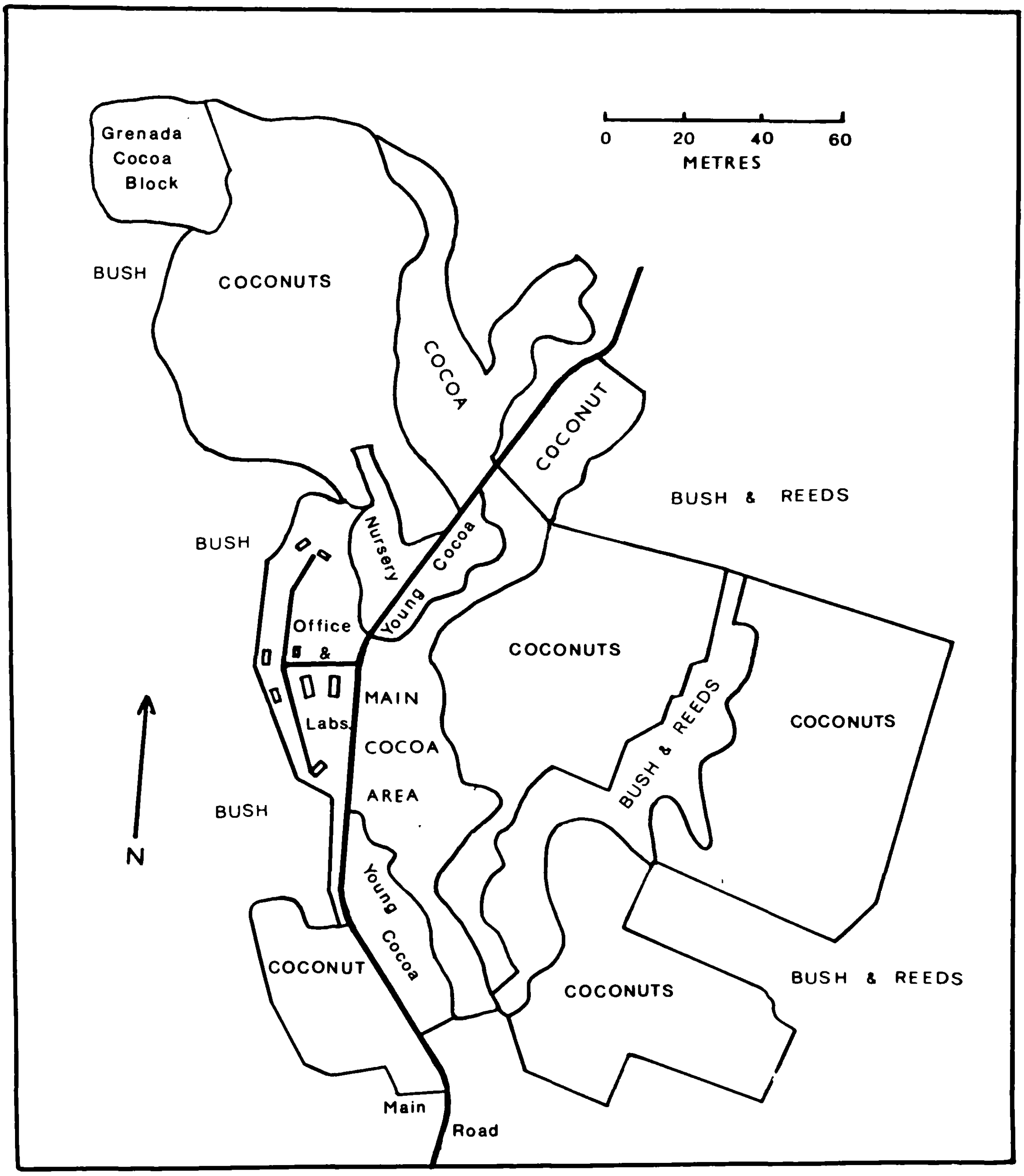
II. Coconuts. Wainigata

Line break-back trapping, as described above, provided some animals for autopsy at irregular intervals and in some cases in small numbers. It was therefore necessary to sample at regular intervals a relatively uniform habitat to obtain sufficient animals for an analysis of seasonal trends in such parameters as reproduction. To achieve this

FIGURE 2.1

WAINIGATA RESEARCH STATION SHOWING THE LOCATION OF THE COCONUT AND COCOA AREAS

All monthly break-back grid trapping was carried out in the coconut areas. Cocoa poison trials were carried out in the main cocoa areas bordering the road. The combined poison and population study was carried out in the relatively remote Grenada cocoa area.


Grenada
Cocoa
Block
0
20
40
60
METRES
BUSH
COCONUTS
COCOA
COCONUT
BUSH & REEDS
BUSH
Nursery
Young Cocoa
Office
&
Labs
COCONUTS
MAIN
COCOA
AREA
BUSH & REEDS
COCONUTS
BUSH
N
Young Cocoa
COCONUT
COCONUTS
BUSH & REEDS
Main
Road

a programme of monthly break-back trapping was carried out at Wainigata Research Station, Vanua Levu, from October 1969 to December 1971. The Research Station covered 117 ha but much of this was steep hillside unsuitable for most forms of agriculture. Approximately 10 ha of valley bottom were devoted to cocoa cultivation and a further 28 ha of undulating country was under coconut palms (Fiji Talls and Malayan Dwarf hybrids) planted between 1960 and 1962. All break-back trapping was carried out in the area under coconut palms which, being part of fertiliser trials, was well maintained by the coconut section of the Research Division. Ground cover consisted of reeds (Miscanthus floridus) and a variety of weeds and grasses (see appendix I, vegetation of Salt Lake coconut area). cut to a height of 30-40 cm (Figure 2.1).

This site was selected because it comprised a relatively large area of similar terrain and uniform management. In addition, it was close to laboratory facilities and staff quarters, an important point, for trap lines had to be checked in the early morning to avoid heat and ant damage to trapped animals.

III. Coconuts. Salt Lake

A mark-recapture trapping programme was established at a site near Salt Lake, Vanua Levu (Figure 2.2), to monitor rat population levels while data on coconut production and damage were accumulated. The area comprised a narrowing valley flat set between two low ridges, the valley being planted with palms 20-25 years old. Ridge slopes carried younger palms (10-12 years), most of which were not bearing nuts. All stands were at a density of 160 per hectare and the height of the older palms varied between 8-11 m. A stream ran down one side of the area along the banks of which

FIGURE 2.2

THE SALT LAKE STUDY AREA SHOWING THE LOCATION AND SPACING OF THE MAIN TRAPPING GRID, OUTER TRAP LINES AND THE 60 SURVEY PALMS

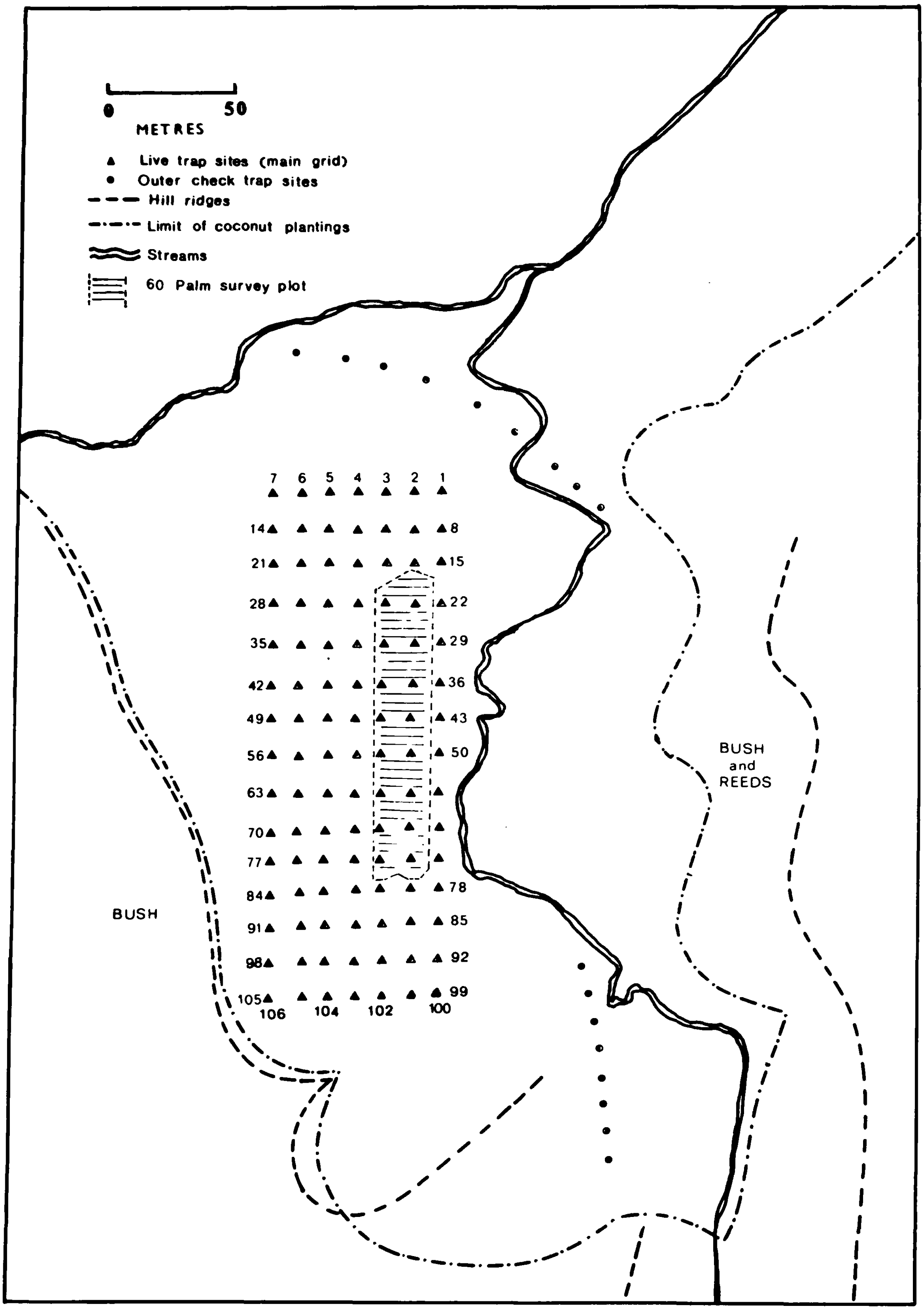

0 50
METRES
Live trap sites (main grid)
Outer check trap sites
Hill ridges
Limit of coconut plantings
Streams
60 Palm survey plot
7 6 5 4 3 2 1
14 8
21 15
28 22
35 29
42 36
49 43
56 50
63
70
77
84 78
91 85
98 92
105 99
106 104 102 100
BUSH
BUSH and REEDS

FIGURE 2.3

GROUND CONDITIONS WITHIN THE SALT LAKE STUDY AREA MAIN TRAPPING GRID.

stood stands of bamboo and several species of forest trees, e.g. Acacia richii, Inocarpus fagiferus, and Podocarpus sp. Vegetation on the plantation floor varied considerably during the year (Section 2.5C) but predominant species were Kaumoce (Cassia tora), Mintweed (Hyptis pectinata), Mile-a-minute (Mikania micrantha) and Sensitive Grass (Mimosa pudica). Guava (Psidium guajava) and various species of Citrus were also scattered through the area (Figure 2.3).

The area was selected because it:

i) constituted a uniform stand of palms short enough to permit individual recording of production (the nutfall from each palm being confined to the area immediately under the crown).

ii) it was remote from human habitation

iii) it appeared to be incurring a moderate level of rat damage

iv) it was owned by a planter sympathetic to the aims of the whole research programme, a very important consideration for a long term project.

v) it was only 10 km by road and foot from Wainigata Research Station.

IV Cocoa. Grenada Block, Wainigata

The cocoa area known as the Grenada block (a Trinatario type cocoa) was selected with the aim of monitoring by mark-recapture, the rat population and damage prior to an attempt at rat control using poisons. Trapping was carried out at approximately two monthly intervals from June 1970 until June 1972. The area consisted of a basin shaped area of 1.4 ha surrounded by a low ridge and separated from all other mature cocoa at Wainigata by low reed covered hills, some planted with young coconuts (Figure 2.4). The cocoa was approximately 10 years

FIGURE 2.4

TWO VIEWS OF THE GRENADA COCOA AREA

Top: Ground conditions under the cocoa canopy

Bottom: Plant cover on the margin of the cocoa plot.

old at a spacing of 3 m square and under heavy shade produced by inter-planted Dadap (Erythrina lithosperma) trees. These trees, with the canopy formed by the cocoa, prevented the development of any herbaceous or grass ground cover with the result that the plantation floor was almost exclusively covered with leaf litter.

V. Cocoa. Waimaro Station, Viti Levu.

Waimaro Station is located on Waimaro stream in the Tailevu area of Viti Levu. It was established in the early 1960's as an experimental cocoa farm and from 1968 was under the management of the Cocoa Section of the Research Division. Cocoa production and damage data for 1968 and 1969 indicated a high level of rat damage and snap trapping in May 1969 revealed the presence of all three species of Rattus. These features made the area suitable for an investigation of the relative importance of the three species as a pest of cocoa. Accordingly the area was subjected to capture-recapture trapping from May 1970 until May 1972.

Waimaro Station consisted of 17 hectares of Amelanado cocoa with some large shade trees scattered throughout the cocoa. The combined canopy of the shade and cocoa trees allowed little vegetation to develop and those that did grow in a few plantation gaps, were controlled with herbicides (Figure 2.5). All cocoa on the station was on flat land, with a small part of it on a stream flat at a lower level. A few small weed and grass filled gullies adjoined the cocoa area but all merged into the improved dairy pastures that completely surrounded the station.

VI. Cocoa. Namara Road, Viti Levu.

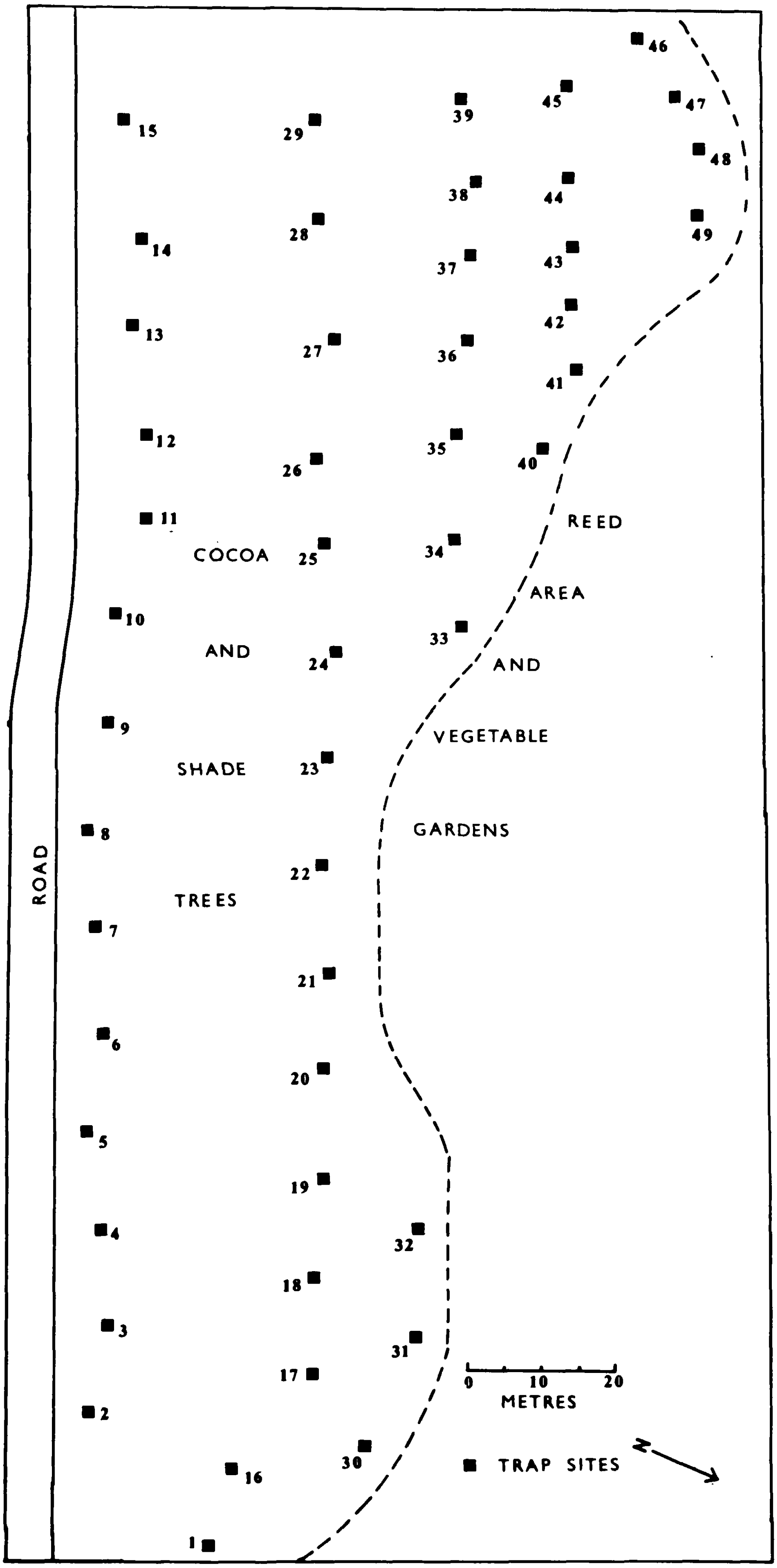
By mid-1971 it was apparent that there were insufficient recaptures at the Waimaro site for estimates of total population that used methods such as those of Jolly (1965) or Manly and Parr

FIGURE 2.5

GROUND CONDITIONS WITHIN THE WAIMARO COCOA STUDY AREA

FIGURE 2.6

NAMARA ROAD COCOA PLOT SHOWING THE LOCATION AND SPACING OF THE TRAP GRID


ROAD
COCOA AND SHADE TREES
REED AREA AND VEGETABLE GARDENS
0 10 20
METRES
TRAP SITES
N
1 2 3 4 5 6 7 8 9 10 11 12 13 14 15 16 17 18 19 20 21 22 23 24 25 26 27 28 29 30 31 32 33 34 35 36 37 38 39 40 41 42 43 44 45 46 47 48 49

(1968). In addition, it was considered that the high level of management on the Research plantations (resulting in no ground cover) could constitute an atypical rat environment. A capture-recapture programme was therefore established on a typical farmer's property on Namara Road, 19 km from Nausori, where production and damage was being recorded weekly (Figure 2.6).

The cocoa plot covere 0.5 ha and consisted of irregularly planted Trinatario type cocoa that had mostly developed into large bushy trees. Large shade trees, Ivy (Inocampus sp.) and Dadap were interspersed throughout the area and the predominant ground cover was Para grass (Brachiaria mutica) particularly in the more open areas. Under the denser cocoa there was little ground cover. Pasture, current and overgrown vegetable gardens and low reed covered hills surrounded the area on three sides, the fourth boundary lying by the road. Trapping at Namara was started in June 1971 and continued until September 1972.

2.2B SURVEY METHODS

I. Break-back trapping

The commercial break-back trap consisted of a wooden base measuring 20 by 10 cm with a conventional spring and flat metal trigger (Figure 2.7). For preservation they were soaked in oil and then air dried for at least a week to allow the possibly offensive odour of the oil to disperse. Fresh coconut was always used as bait. In this context it is worth noting that Hood et al. (1967) found that coconut was consistently favoured by R. rattus, R. exulans and R. norvegicus in Hawaiian sugarcane, even when baits such as apple and corn-on-the-cob were present. A new bait was placed on all traps daily.

FIGURE 2.7

BREAK-BACK TRAPS IN LOCATION NAILED TO A PALM TRUNK AND TIED TO GROUND VEGETATION.

For general trapping throughout Fiji a standard trap line was employed. It consisted of 25-30 traps set out at 10 pace intervals along an arbitrary line through a plantation and usually followed a line of palms or cocoa trees. Small clearings were made in the undergrowth for ground placed traps. In coconut plantations rows of 25 - 30 traps were also nailed to the trunks of palms about 3 m from the ground and at least 20 m from any ground trap lines. Tree trap lines in cocoa plantings were placed in the first fork (termed jorquette) of each tree and tied in place with string or vine. All traps on ground lines were secured with a length of cord to prevent the Indian mongoose (Herpestes auropunctatus) and crabs from removing traps containing rats. The mongoose, which was only present on the two largest islands (Viti Levu and Vanua Levu), mutilated a small number of animals caught in ground traps. However it was usually possible to identify the species caught even when a full autopsy (as detailed below) was not possible.

All general trap lines were set for three or four consecutive nights except on some outer islands where transport limitations allowed only one or two nights trapping.

In the Wainigata coconut area a grid of 81 break-back traps consisting of nine rows of nine traps at a regular spacing of 10 m was employed for four nights each month. To ensure consistent trap spacing and overall grid size, a series of ropes graduated at 10 m intervals were laid out a measured 10 m apart and traps set at the designated points. Each month the trapping grid was placed at a new site at least 100 m from the previous one, and in many cases considerably further apart. A grid of traps was used in preference to the lines described above, as this enabled a maximum likelihood estimate of population size to be obtained each month by calculating the maximum likelihood estimate of p (the probability of capture during a single trapping), as described by Zippin (1958). This estimate of population size could then be compared with estimates derived from mark-recapture studies carried out at other sites. Grid trapping has been widely used by Polish ecologists, and the I.B.P. working groups on small mammals have proposed adopting, as the basis for investigations of small rodents, a uniform sampling method consisting of a grid of 16 rows and lines at 15 m intervals. This layout was tested by Grodzinski et al. (1966) and was found to give satisfactory estimates of population numbers when a regression lines was fitted to daily capture rate (x) versus cumulative number of rodents previously caught (y), the method of Hayne (1949). However, Pelikan (1971) established that grids of only 0.56 ha gave very similar density estimates, of microtine rodents, to the I.B.P. grid.

Traps were set, checked and rebaited with fresh coconut each day and the field data noted according to row and trap number. It included species caught, traps sprung without catch, and the presence of absence of bait on all traps except those containing rats. Subsequent autopsies recorded the following information for each animal.

a) Species
b) Sex
c) Date caught
d) Site caught
e) Weight
f) Total length
g) Tail length
h) Right hind foot length
i) Right ear length
j) Sexual condition

Sexual condition included, for females, the condition of the vagina and whether or not it was perforated, the condition of the uterus and the presence or absence of uterine scars and if pregnant the length of the embryo. For males the position and length of the testis were recorded.

In addition the head was preserved in 10 percent formalin for age to be determined using the eye lenses. Some stomachs were collected for diet analysis. The length measurements, noted above, were carried out following the British Museum Method advocated by Corbet (1964). The animal was laid supine on a measuring board and the base of the tail found by sliding a pencil or seeker along the tail until it met with resistance from the pelvic girdle. Total length and tail length were recorded to the nearest millimetre with head and body lengths derived by subtraction.

Such a programme of removal trapping was confined to a coconut area as no continuous areas of cocoa were large enough.

II. Mark recapture trapping

a) Trap types

Two types of traps were used during mark-recapture programmes, the first confined to the coconut study at Salt Lake, the second used at all sites. The first type, of which 55 were purchased from Elliot Scientific Limited, Melbourne, were made of plate aluminium and constructed to fold flat for transportation. The trigger consisted of a plate in the base of the trap which an animal had to pass over to reach the bait placed on the floor at the rear. The trap when set for use measured 33 by 9.5 by 9.5 cm (Figure 2.8).

The second type, of which 360 were purchased from Japan, were made of wire mesh measuring 24 x 18 x 10 cm (Figure 2.9), and were designed for multiple catching, the latter feature not being used however, because the wires forming the central funnel made the trap difficult to bait. Since Hood (pers. comm.) reported that R. exulans could escape via this second entrance the top mounted funnel was closed and the traps used for single

FIGURE 2.8

AN ALUMINIUM FOLDING TRAP, USED AT SALT LAKE

FIGURE 2.9

A WIRE CAGE TRAP IN LOCATION AT SALT LAKE

The trap is in the sprung position and contains a R. exulans.

captures via the spring loaded front entrance. Bait was placed on a wire arm at the rear of the cage.

The folding aluminium trap was the first type purchased and, although very convenient for field transport, the high cost (F$3.00 each) precluded the use of large numbers. The Japanese wire trap,in contrast, cost F$0.45 and while bulky proved to be more satisfactory, having a consistently higher capture rate than the aluminium type (Section 2.4).

b) Survey procedures

At the Salt Lake site a grid of 105 traps, at a spacing of 15 m was established (Figure 2.2.) Trapping was carried out for three nights per month from January 1970 until September 1972. Aluminium and wire traps were used throughout the study with each type placed at alternative sites and these in turn were changed from one month to the next. Traps were checked and rebaited daily with fresh coconut.

Such grids are widely used for population estimates based on mark-recapture trapping and virtually all methods are based on the important assumption that the probability of capture is the same for all members of at least an identifiable portion of the trapped population. However, various sets of data (Seber, 1965; Cormack, 1966) indicate that the equal-probability-of-capture assumption is not fulfilled, at least by usual trapping methods. Both the methods used to analyse the results of this population study (Jolly, 1965 and Manly and Parr, 1968) make this assumption and while they currently constitute two of the most sophisticated methods available (requiring the minimum number of assumptions in other respects) some attempt had to be made to increase equal capture probabilities. Eberhardt (1969) suggested that since most live-trapping is done on a square grid layout, a minimal precaution would be the shifting of the trap locations after perhaps half the planned number of trap nights had elapsed. During the survey this idea was implemented by shifting the traps, which were located within a five metre radius of the marker peg, to another clump of vegetation at least five metres away, whenever an animal was caught. It was hoped that this would increase the likelihood of a different animal locating the resett trap, thereby reducing the catches of so called 'trap happy' animals.

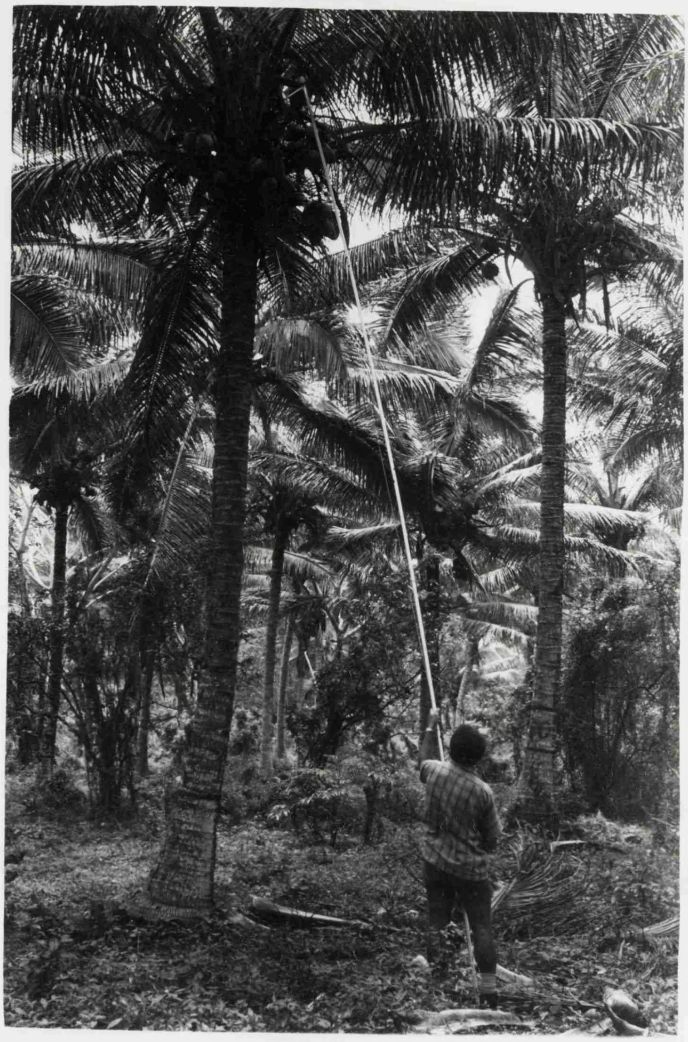
In addition to the major grid at Salt Lake, two lines of approximately eight wire traps, at 15 m intervals, were also run each month at sites 50-80 m from each end of the grid (Figure 2.2). These were to check long distance movements into and out of the main grid.

From April 1972 regular trapping of palm crowns was carried out after a long handled tool had been developed to lift traps into and out of palm crowns (Figure 2.10). An early attempt at crown trapping in this area had involved an inordinate amount of time and effort and for financial reasons could not be continued. Using the tool, 20-30 wire traps were placed on level parts of lower fronds for three nights per month.

All animals trapped were marked in the right ear with a numbered fingerling tag. Rats were handled in a clear heavy-weight polythene bag with the ear pulled out through a small slit near one of the bag corners (Figure 2.11). This method of handling proved much more efficient than any of those outlined by Southern (1964). Data recorded for each animal included species, sex, vaginal and scrotal condition, weight

FIGURE 2.10

THE TOOL USED TO LIFT TRAPS INTO THE PALM CROWN (TOP) AND A WIRE TRAP IN LOCATION ON A LOWER FROND (CENTRE OF LOWER PHOTO)



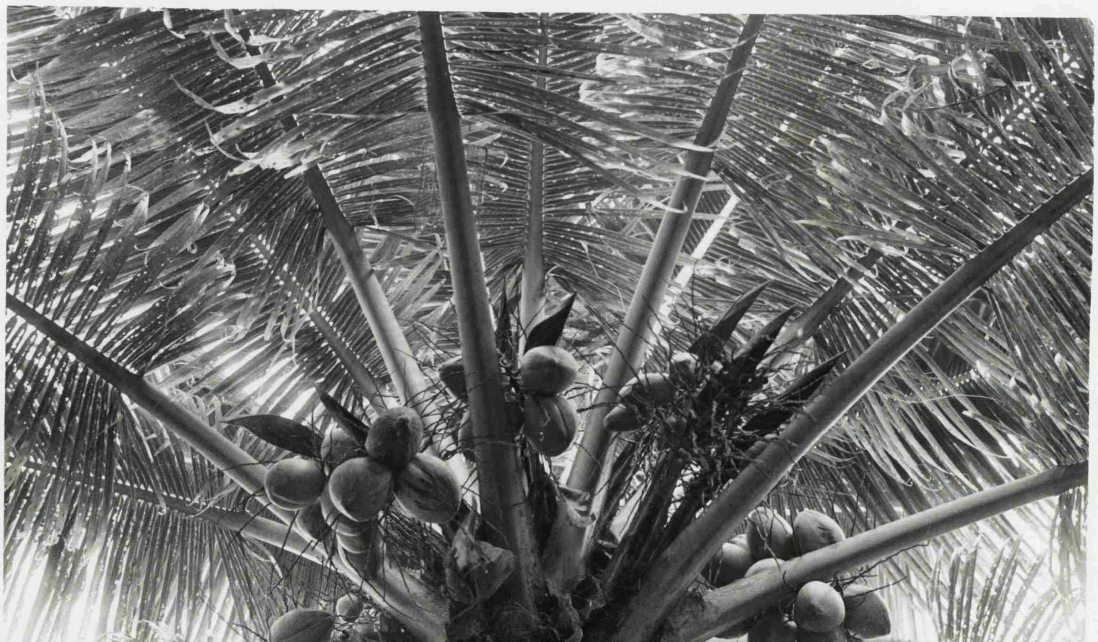


FIGURE 2.11

METHOD USED TO EXAMINE AND TAG ALL RATS

After rats had jumped from the trap they were confined in the corner of the polythene bag for examination and for tagging the ear was pulled out through a slit cut in the corner.

and site of capture.

As a major aim of the Salt Lake population study was to investigate a possible relationship between rat numbers and level of coconut damage 60 palms within the trap grid area were selected for continuous recording of damage and production. Selection of palms simply involved the inclusion of all palms in four rows of 15 palms per row (Figure 2.2). Recording was done monthly. Undergrowth around the immediate base of all palms was kept cut to ensure all nuts could be found.

The amount and composition of herbaceous vegetation varied greatly throughout the year and it was thought that there might be a relationship between rat numbers and both type and amount of such vegetation. Accordingly a simple plant survey was carried out monthly from April 1971 to April 1972. A simple plot method was adopted with samples being taken on a line one metre from each trap location on the grid. At each point a measuring pole was placed and details of the vegetation within a 0.5 m diameter circle recorded. Data included height and name of the predominant species, the names of other significant plants, and the percentage ground covered by all species.

Trapping and data recording procedures at the three cocoa plantation sites, Grenada, Waimaro and Namara, were similar to those detailed for Salt Lake. The major exception was the placing of two wire traps at each trap point on the grid, one on the ground and the other in the first fork (jorquette) of the nearest cocoa tree. Trap spacing at Grenada and Namara sites was at about 15 m intervals with each site being accurately mapped to enable movement data to be derived from trapping records. The Grenada and Namara grids consisted of 60 and 49 trap sites respectively. Waimaro grid consisted of 75 sites at a spacing of 12.5 m and in addition to the trapping procedures described for Salt Lake, an investigation of trap avoidance behaviour was made. Smoked paper strips were placed around the branches fanning out from the jorquettes in which traps were located and the frequencies of visits noted.

At all sites the amount of cocoa harvested and rat damaged was recorded regularly, usually weekly, as part of an overall study of the crop at Grenada and Waimaro, but specifically to relate rat population levels to damage at Namara Road.

2.3 DISTRIBUTION AND RELATIVE ABUNDANCE OF RATTUS SPECIES IN FIJI

R. exulans was clearly the most widespread species in Fiji as it was trapped at 35 of the 38 trap sites (Figure 2.12). Grid trapping studies (Section 2.4A) showed that most animals were caught at ground-placed traps, reflecting the vertical distribution of the species (Section 2.4C)

R. rattus was also fairly widespread on the main islands, but on three of the Lau Islands, Matuku, Lakeba and Yacata, no R. rattus were trapped. Because this species favours palm crowns at night (Section 2.4C) this result did not indicate total absence of the species but suggested that they are relatively rare on some of the outer islands. The virtual absence of rat-damaged coconuts on Matuku and Lakeba supported these trapping results as it was established that R. rattus was responsible for most of the damage in mature coconut groves (Section 3.2).

R. norvegicus was found at only seven of the trapping sites,

FIGURE 2.12

THE DISTRIBUTION OF RATTUS SPECIES IN FIJI

Based on survey trapping in major coconut and cocoa growing areas.

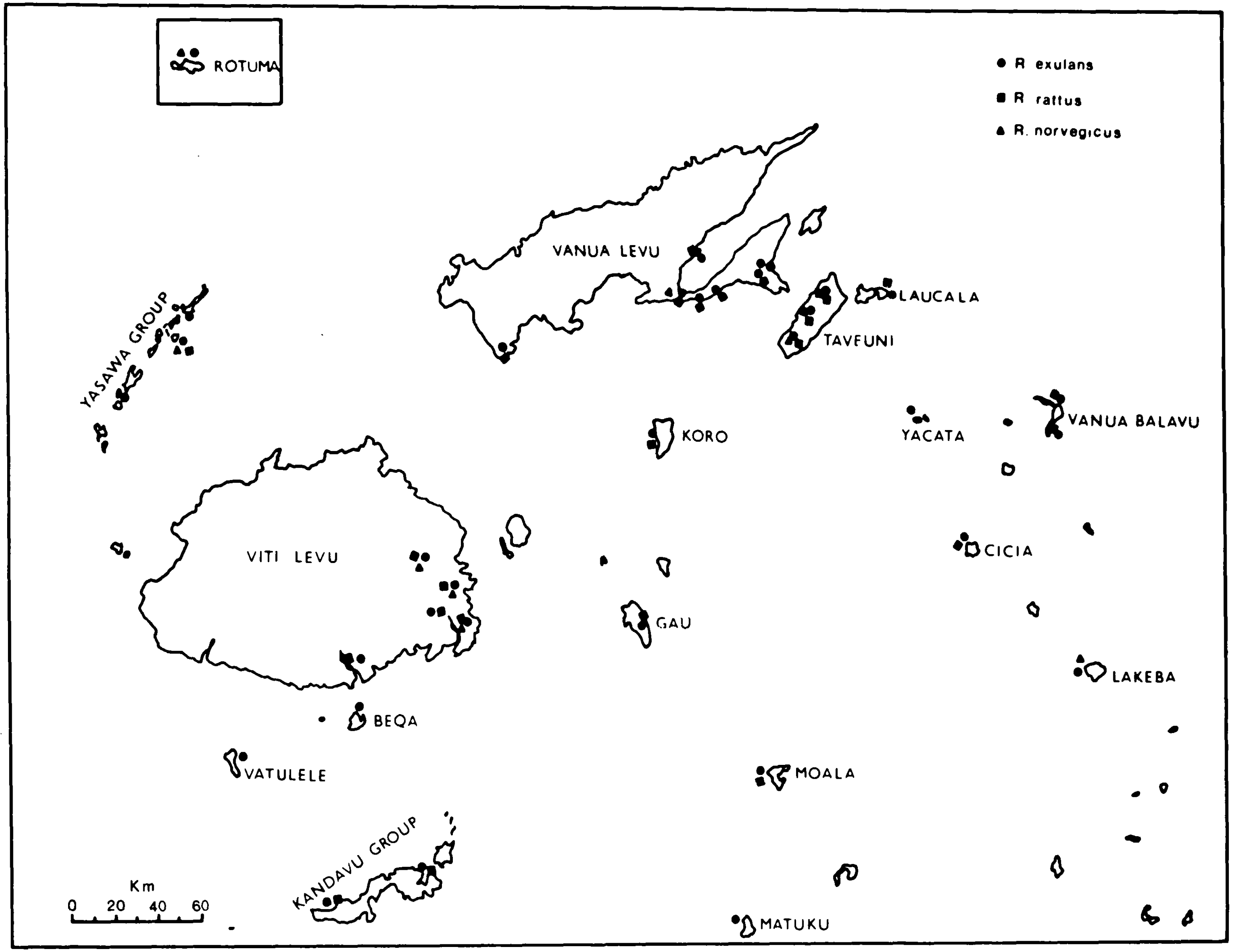

ROTUMA
R exulans
R rattus
R. norvegicus
VANUA LEVU
LAUCALA
TAVFUNI
YASAWA GROUP
KORO
YACATA
VANUA BALAVU
VITI LEVU
CICIA
GAU
LAKEBA
BEQA
VATULELE
MOALA
KANDAVU GROUP
Km
0 20 40 60
MATUKU

FIGURE 2.13

RELATIVE ABUNDANCE OF RATS IN COCONUT PLANTATIONS AND GROVES

ON THE ISLANDS OF VITI LEVU, VANUA LEVU AND TAVEUNI. A-N = TRAP AREAS

A = Waitavala Estate, Taveuni

B = Mua Estate, "

C = " " "

D = Waitavala Estate "

E = " " " "

F = Benau Estate, Vanua Levu

G = Groves at Korotasere, "

H = Levuka Lailai Estate "

I = Grove, Tovata Road, Viti Levu

J = " " " "

K = " " " "

L = Wainiyaku Estate, Taveuni

M = Groves, Natauwalu area, Vanua Levu

N = Tuvamaca Estate, Taveuni

Key: Open histogram = rats caught in ground placed traps

Solid histogram= rats caught in traps nailed to palm trunks

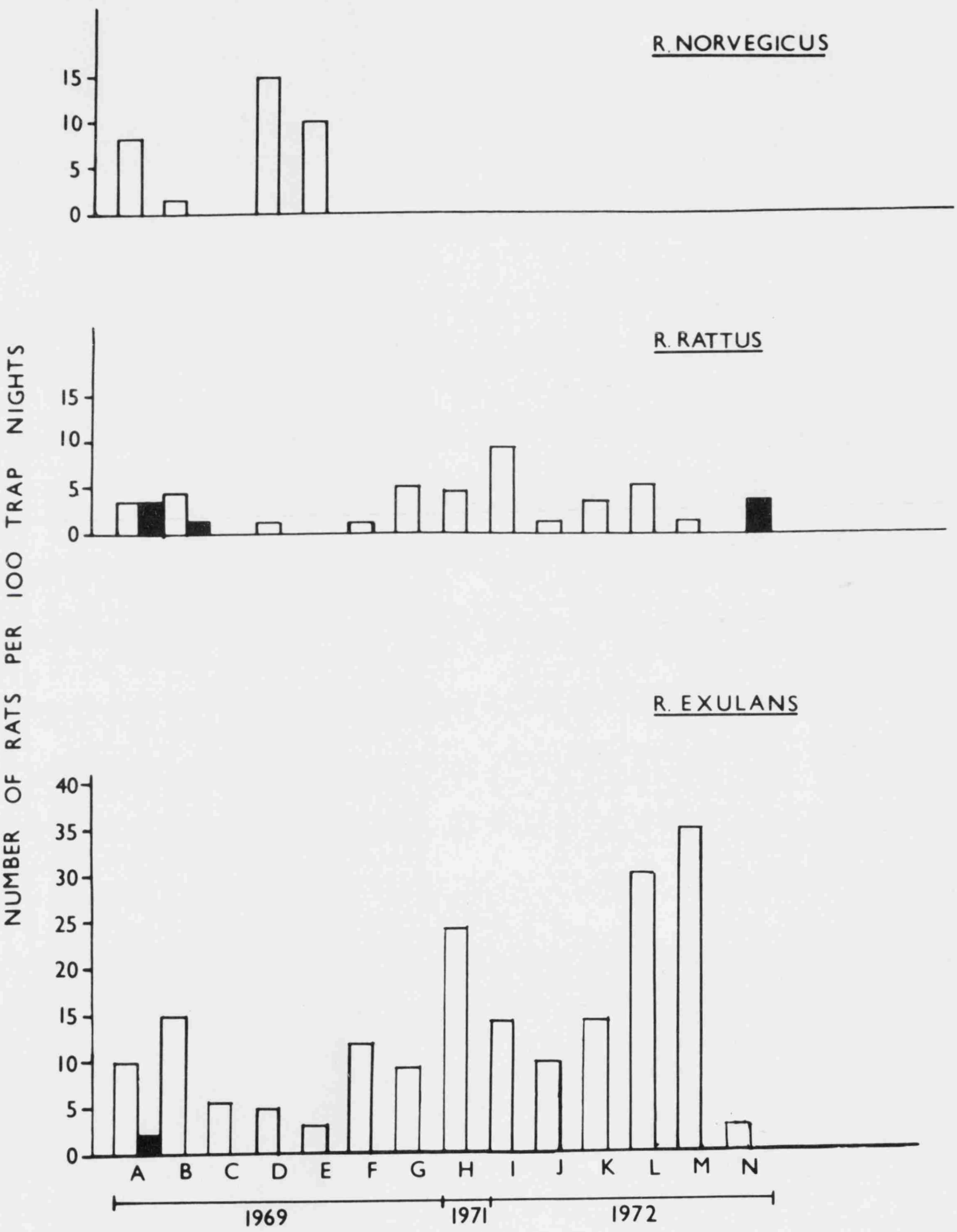

R. NORVEGICUS
R. RATTUS
R. EXULANS
NUMBER OF RATS PER 100 TRAP NIGHTS
0
5
10
15
20
25
30
35
40
A B C D E F G H I J K L M N
1969
1971
1972

FIGURE 2.14

RELATIVE ABUNDANCE OF RATS IN COCONUT GROVES ON FIJI'S OUTER ISLANDS. A - P = TRAP AREAS

A = Matuku Island

B = Moala Island

C = Lakeba Island

D = Vanuabalava Island

E = " "

F = Laucala Island

G = Yacata Island

H = Cicia Island

I = Beqa Island

J = Vatulele Island

K = Yasawa Island

L = Nauya Lailai Island

M = Naukacavu Island

N = Rotuma Island

O = Kadavu Island, Vunisea

P = " " Nakasaleka

Key: Open histogram = rats caught in ground placed traps

Solid histogram = rats caught in traps nailed to palm trunks

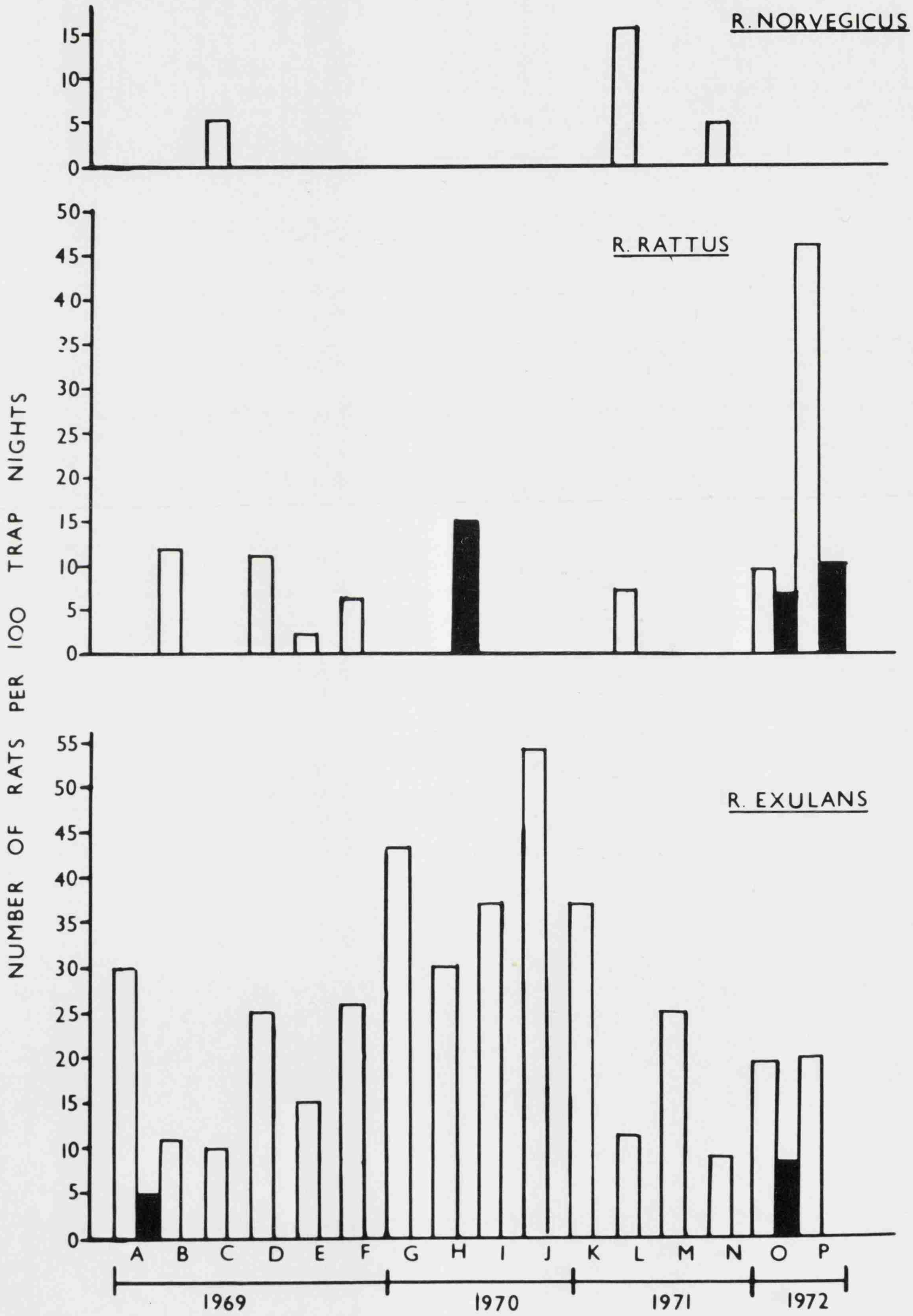

R. NORVEGICUS
R. RATTUS
R. EXULANS
NUMBER OF RATS PER 100 TRAP NIGHTS
0
5
10
15
20
25
30
35
40
45
50
55
A
B
C
D
E
F
G
H
I
J
K
L
M
N
O
P
1969
1970
1971
1972

FIGURE 2.15

RELATIVE ABUNDANCE OF RATS IN FIJI COCOA GROVES A - H = TRAP AREAS

A = Waimaro Research Station, Viti Levu

B = Koro Island

C = Gau Island

D = Namara Road Farm, Viti Levu

E = Nandruloulou Research Station, Viti Levu

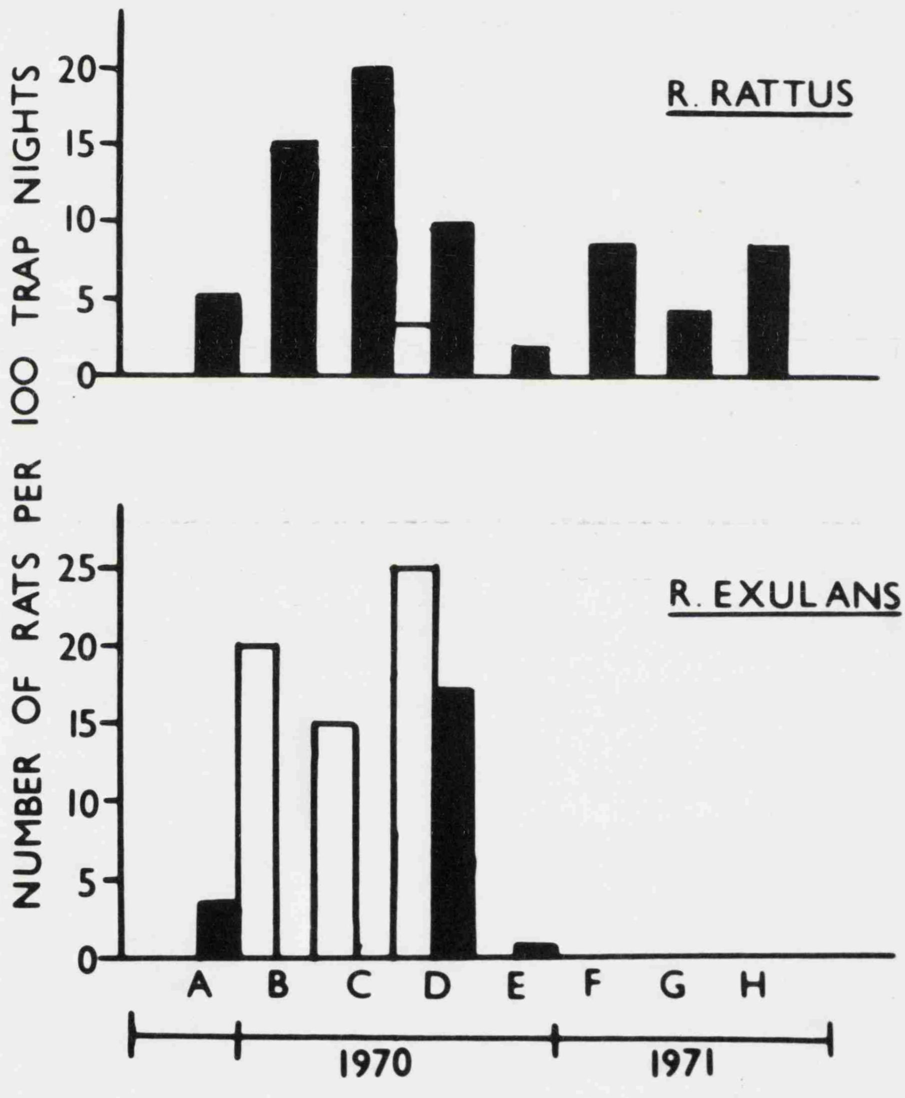
F = Loa cocoa farm, Vanua Levu

G = Navonu " " "

H = Nagigi " " "

Key: Open histogram = rats caught in ground placed traps

Solid histogram = rats caught in traps in first fork of cocoa tree


R. RATTUS
R. EXULANS
NUMBER OF RATS PER 100 TRAP NIGHTS
0
5
10
15
20
25
A
B
C
D
E
F
G
H
1970
1971

indicating that it was a relatively unimportant rat in Fiji's rural environment. In the Lau Islands, it was trapped only in small numbers within the village of Tobou on the island of Lakeba, and village elders thought that it originated from ships that were wrecked late in the 19th century. R. norvegicus was also trapped on the islands of Rotuma and Nauya Lailai in the Yasawa group both also sites of ship wrecks in the last century. The greatest concentration of R. norvegicus in a plantation habitat was on Waitavala Estate, Taveuni (Figure 2.13). R. exulans, R. rattus and Mus musculus were also trapped in the same area indicating that the relatively simple habitat of a well maintained mature coconut plantation is capable of supporting four rodent species. However the results showed that the presence of four species in one area was not widespread. (Figures 2.13, 2.14 and 2.15).

Break-back trapping can provide a measure of relative abundance if results are expressed as rats per 100 trap nights (or similar units), with a "trap night" representing the exposure of one trap for one night, an approach applied to rodents in Africa (Neal, 1970) and to Rattus species in the Pacific (Jackson and Strecker, 1962). Some authors have attempted to correct for trap interference (Jackson and Strecker, 1962) as considerable variation between trap sites affects the estimates of relative abundance. However as trap interference during this study was minimal, no correction factor was necessary.

R. exulans was clearly more abundant than either of the other species in nearly all the habitats sampled (Figures 2.13, 2.14 and 2.15). During 1970, relative numbers were particularly high, a feature confirmed by absolute population estimates (Section 2.5C). R. rattus did not seem particularly abundant at any of the coconut sites trapped, but this may have been a reflection of trap location. A comparison between R. rattus captures in the palm crown and on the ground revealed that the species was more likely to be caught in the arboreal sector of the habitat (Section 2.4C), an aspect also clearly seen in cocoa plantations where most animals were caught in the trees. Significant numbers of R. norvegicus were found at only two sites, Waitavala Estate Taveuni and Nauya Lailai Island, and in general this species did not appear to have successfully invaded the Fijian rural environment, a feature common to species in many tropical areas (Searle and Dhaliwal, 1957; Johnson, 1962).

2.4 POPULATION BEHAVIOUR IN RELATION TO THE PHYSICAL ENVIRONMENT

2.4A RESPONSES TO TRAPS

Although the prime aim was to investigate rat interaction with two crops it was also desirable to determine how animals interact with the sampling tools used, as ultimately all population parameters are dependent on the nature of trap sampling. Therefore measures of any major biases are fundamental to an assessment of results.

I. Differences between trap types.

As outlined in Section 2.2B, two types of traps were used at the Salt Lake site. Using data from 1989 trap nights (ground placed) between May 1970 and December 1971, the capture rates were recorded (Table 2.1).

Wire traps captured significantly more animals ($p = > 0.01$) than the aluminium and were the only type to catch R. rattus. This marked difference was probably due to the enclosed nature of the aluminium traps, although the long narrow shape may also

Table 2.1 THE DISTRIBUTION OF CAPTURES BETWEEN TWO TRAP TYPES

Captures per 100 trap nights			Percentage of total captures	
Aluminium	Wire		Aluminium	Wire
R. exulans	R. exulans	R. rattus	R. exulans	R. exulans + R.rattus
21.0	38.8	1.4	36.5	63.5

Note: Each trap type laid alternately throughout the grid

have been a factor. In addition, aluminium traps tended to become soiled and attempts were made, by regular washing, to reduce any repellant effect that species or sex specific contamination may have caused. Jackson and Strecker (1962) noted that sheet metal traps caught fewer rats than wire mesh, when trapping a mixed Rattus population, while Holdenried (1954) and Hansson (1967) have also reported lower catches of small rodents (Microtine) in solid-walled when compared with the open-meshed type. Nevertheless, this is not a general phenomenon as Chitty and Kempson (1949) found no difference between the two types when trapping mice, indicating a different response to trap type between different mammals. Neal and Cock (1969) found such species' responses to be very marked during trapping studies of small African mammals, noting that differntial species' responses to traps remained even after correcting for the effect of differences in the mean weight of species.

Despite these differences in capture rates, the aluminium traps were used throughout the Salt Lake study because these differences only became apparent after several months. By then it was considered inappropiate to alter the trap layout, particularly as it was unlikely that the differences would have a marked effect on population estimates, as the number of new captures and recaptures always remained high enough to permit the derivation of reliable estimates (Section 2.5C).

Since break-back traps were also used extensively throughout the whole study it was desirable to determine how the capture rates of R. exulans and R. rattus in this type compared with those from wire and aluminium cage traps.

Capture rates on the first day of trapping each month at Salt Lake (wire and aluminium types) and Wainigata (break-back) indicated, at least for the predominantly R. exulans populations, that capture rate for the wire and aluminium types exceeded that of the break-back (Table 2.2A). However, this comparison was not strictly valid for the Salt Lake data included recaptured rats and, as discussed below, such animals enter traps more often on the first day of trapping, in any recapture period, than do animals encountering traps for the first time (Figure 2.16). There was thus probably little overall difference in capture rates between the two trap types under these ground-trapping conditions. To determine if R. rattus responded differently to the wire-cage and break-back traps when set in the palm crown, the capture rates of the two trap types were compared (Table 2.2B). Break-back traps clearly had a much higher capture rate than the wire cages, a result almost certainly due to the fact that this species clearly avoided cage traps (part III below).

II. Recapture characteristics

The appearance in trapping results of trap-shyness (too few captures) and trap-addiction (too many captures) in addition to density, species and sex-induced differences in capture frequency, has been reported by numerous authors for a variety of small rodents (Young et al., 1952; Davis and Emlen, 1956; Davis, 1955; Crowcroft and Jeffer, 1961 and Kikkawa, 1964). Trap-shyness and addiction clearly constitute an inherent problem in population studies based on multiple recaptures.

Table 2.2 RELATIVE CAPTURE RATES OF CAGE AND BREAK-BACK TRAPS

(Data for first day of trapping at each site each month)

A. Ground Trapping

	Salt Lake (Cage traps)			Wainigata (Break-back traps)		
Month	No. rats caught	No. trap nights	Rats per 100 trap nights	No. rats caught	No. trap nights	Rats per 100 trap nights
1970						
May	50	105	48	43	81	53
June	61	105	58	32	81	40
July	35	105	33	38	81	47
Aug.	43	105	41	20	81	25
Sept.	31	105	30	8	81	10
Oct.	37	105	35	17	81	21
Nov.	34	105	32	19	81	24
Dec.	32	105	30	22	81	27
1971						
Jan.	39	105	37	19	81	24
Feb.	-	-	-	35	81	43
March	63	105	60	35	81	43
April	39	105	37	21	81	26
May	39	105	37	-	-	-
Means			40			32
SE			3			4

B. Palm Crown trapping at Salt Lake

Trap Type	No. trap nights	No. rats caught	Rats per 100 trap nights
Wire cage	414	12	2.9
Break-back	168	9	4.7

Nevertheless it was not considered appropriate, within the terms of the present study, to investigate them in detail.

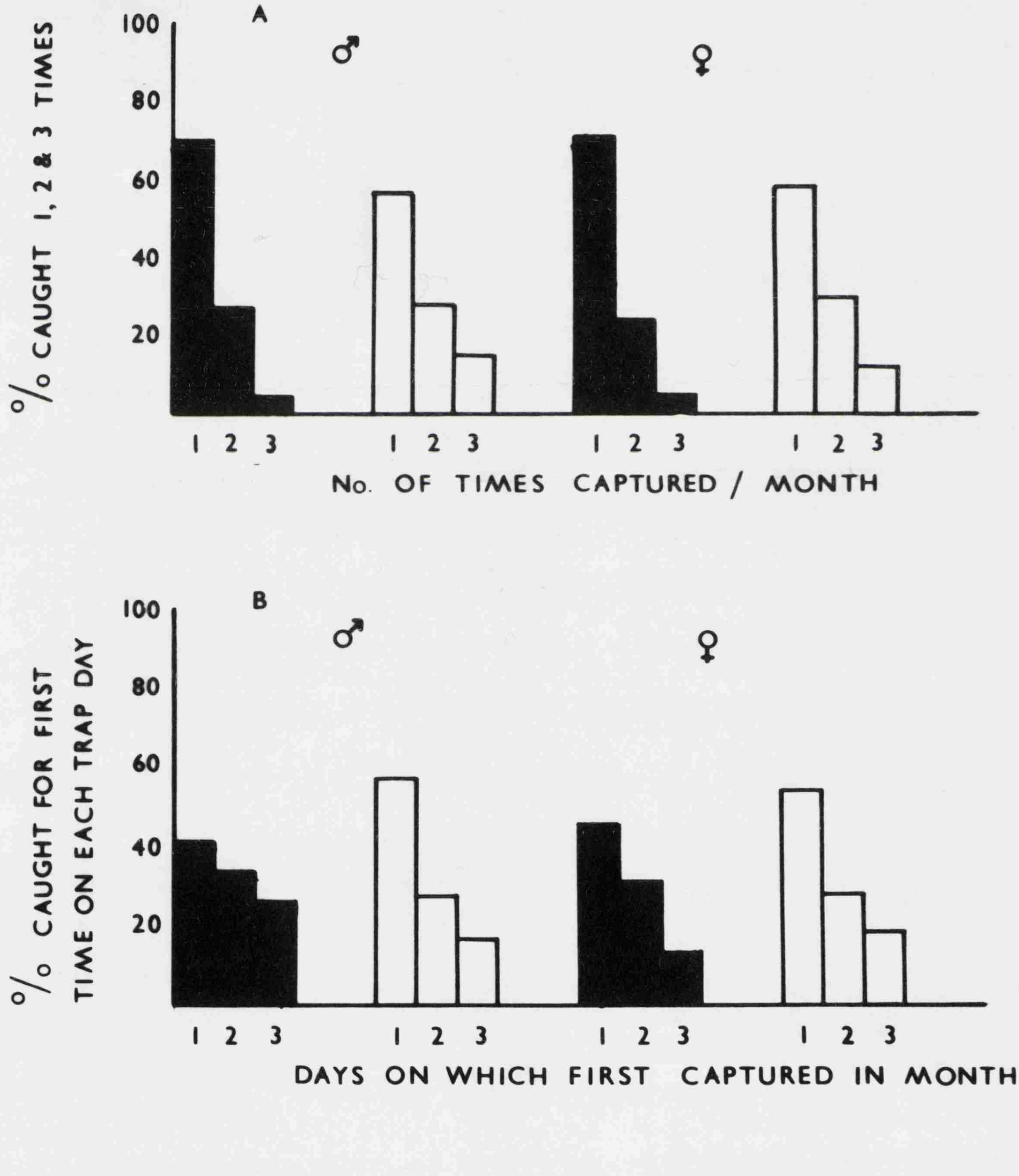
However some measure of these biases was desirable so a record was made of the day on which each animal was first captured in each month and whether it was caught again in the same month. The day and number of times it was recaptured in subsequent months was also recorded (Figure 2.16A and B). There was a significant increase in the number of animals caught two or three times in the months after their initial capture. This behavioural change was common to both sexes of R. exulans in the Salt Lake population and was exemplified by the marked increase in the percentage of animals caught three times (Figure 2.16A). There was also a change in the daily pattern of first captures with fewer animals being caught on the first day of the month in which they were first captured, than in subsequent months of capture (Figure 2.16B). Both these changes in capture frequency suggested a pattern of learning which reduced the rats' avoidance response, thereby increasing the number of captures on the first day of trap encounter in recapture months, as well as increasing the number of captures per month. It should be noted that this change in 'day of capture behaviour' was significant only for males, suggesting that they exhibited stronger avoidance behaviour than females on their first trap encounter. Since such behaviour was subsequently modified by repeated trap encounters, the overall recapture rate of males and females in subsequent months was similar (4.06 per 100 trap nights for males and 4.14 per 100 for females).

The initial capture rate of males and females should be considered at this point, to determine whether there were any differences between the sexes and to what these may be ascribed.

FIGURE 2.16

A. PERCENTAGE OF RATS CAUGHT ONCE, TWICE OR THREE TIMES DURING THE FIRST TRAPPING PERIOD CAPTURED, AND IN SUBSEQUENT PERIODS

B. PERCENTAGE OF RATS CAUGHT FOR THE FIRST TIME ON DAY ONE, TWO AND THREE DURING THE FIRST TRAPPING PERIOD CAPTURED, AND IN SUBSEQUENT PERIODS


A
B
100
80
60
40
20
♂
♀
% CAUGHT 1, 2 & 3 TIMES
1 2 3
No. OF TIMES CAPTURED / MONTH
% CAUGHT FOR FIRST TIME ON EACH TRAP DAY
DAYS ON WHICH FIRST CAPTURED IN MONTH

Break-back trapping probably yields a better estimate of sex ratios in rat populations than cage trapping because variables such as the reduction in the number of traps available (by trap addicted mammals), social dominance, and avoidance of behaviour have little impact.

Data for 1157 R. exulans from Wainigata showed a sex ratio of 46.6 percent male and 53.4 percent female, a deviation from parity. Assuming that this was a representative sex ratio, and that such a ratio would have been found in R. exulans populations in the Wainigata/Salt Lake area in1970, 1971 and 1972, the ratio of males to females caught in cage traps at Salt Lake (49.3 percent female, 50.7 percent male) suggested avoidance behaviour by the females. Calhoun (1962) working with an enclosed Norway rat population of a known sex ratio of one to one, found that males were trapped more frequently than females on the first trapping occasion and during subsequent recaptures. While there was little difference between the recapture rate of both sexes of R. exulans, the apparentunder-representation of females in the cage-trapped population, compared with the sex ratio derived from break-back trapping, could have been a manifestation of a female avoidance response.

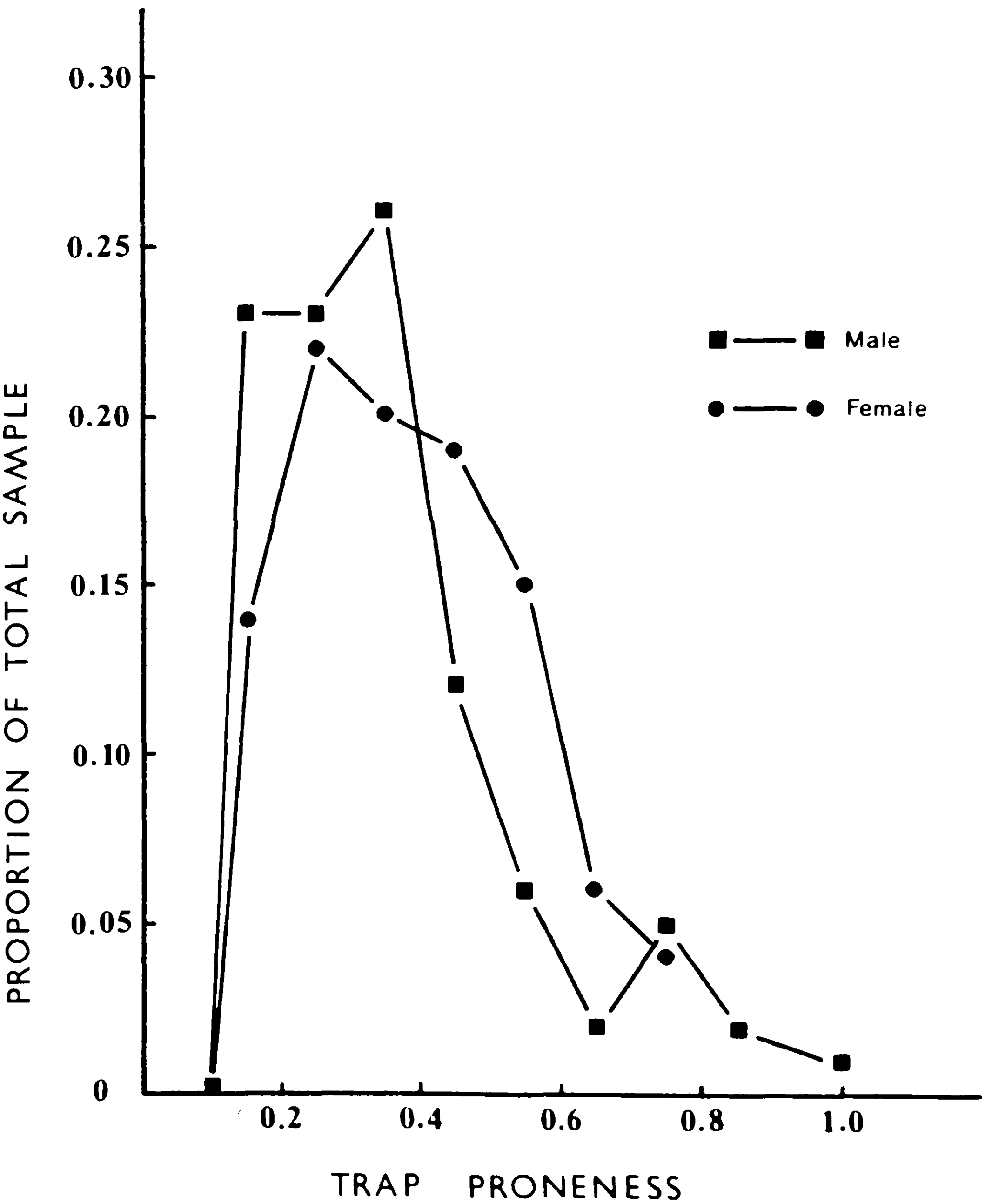
In addition to overall changes in R. exulans response to traps, there was also considerable variability between individuals This can be illustrated by constructing a trap-proneness index:-

$$\text{Trap proneness} = \frac{\text{Number of times captured}}{\text{Number of times exposed to capture}}$$

Such an index was derived for all animals known to survive four or more months at the Salt Lake grid (Figure 2.17). Some of the animals with low-trapping proneness were probably caught

FIGURE 2.17

RELATIVE TRAP PRONENESS OF R. EXULANS KNOWN TO REMAIN IN THE POPULATION FOR AT LEAST FOUR MONTHS



0.30
0.25
0.20
0.15
0.10
0.05
0
0.2
0.4
0.6
0.8
1.0
Male
Female
PROPORTION OF TOTAL SAMPLE
TRAP PRONENESS

in traps at the margins of the grid and during some trapping periods could have been outside the grid. However, in general it can be assumed that the left hand slope of the curve represents animals that tended to avoid traps, even though they were in the 'trappable' portion of the population, while the right represents trap addicted animals. Clearly, a few males showed marked trap addiction although there was no significant difference (t = 1.4) between the mean trap-proneness of the two sexes.

III. Trap avoidance behaviour in cocoa

During cage trapping at Waimaro during 1970 it became apparent that the predominantly R. rattus population (Section 2. 5C) was probably avoiding traps, for captures were mostly juveniles and there were few recaptures.

To determine the number of visits made to traps placed in the first jorquette, strips of smoked paper (adding machine paper passed through an airless butane flame) were clipped around at least two branches fanning out from the jorquette, with one placed 20-30 cm in front of the trap entrance (Figure 2.18). Rat foot prints were clearly visible on the smoked surface, their ledgibility having been initially tested in a laboratory trial (Figure 1.19). A trap was recorded as having been visited if one or more of the strips had been crossed during the night.

A very high proportion of traps were visited each night (Table 2.3) but only 7.6 percent of these actually trapped animals. In many cases, it was clear that the rat must have walked around or even over the trap. Although it was not always possible to distinguish R. rattus from R. exulans foot prints it was assumed, on the basis of Salt Lake trapping rates, that there was no marked trap avoidance by

FIGURE 2.18

WIRE CAGE TRAP IN POSITION ON A COCOA TREE WITHIN WAIMARO PLOT, WITH SMOKED PAPER STRIPS ON APPROACH BRANCHES

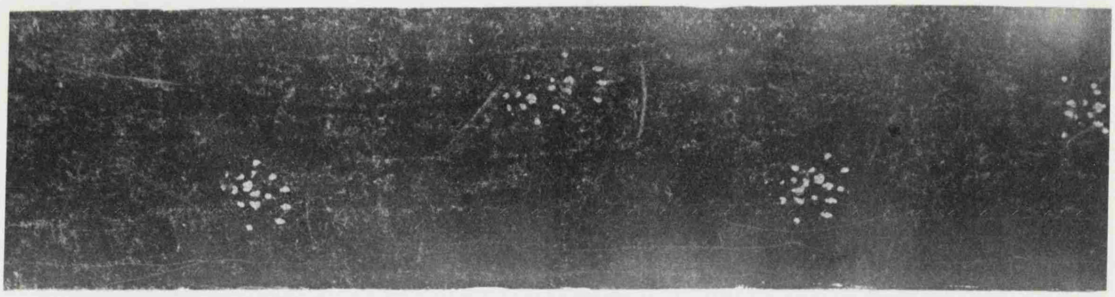
FIGURE 2.19

A. R. EXULANS FOOTPRINTS ON SMOKED PAPER STRIPS

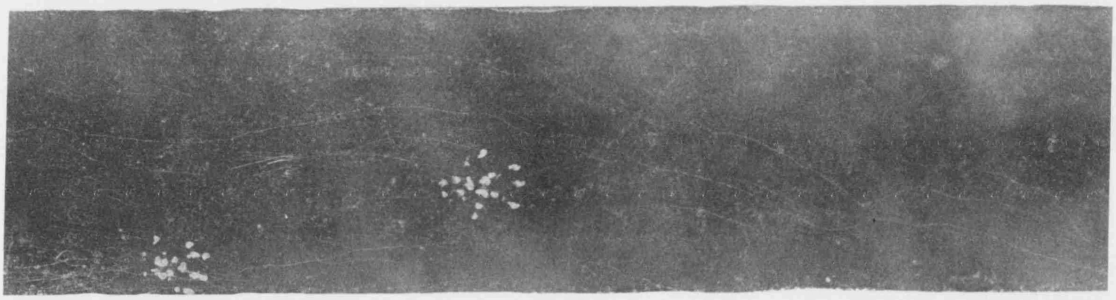
TOP: Level surface slow walk
BOTTOM: Level surface rapid walk

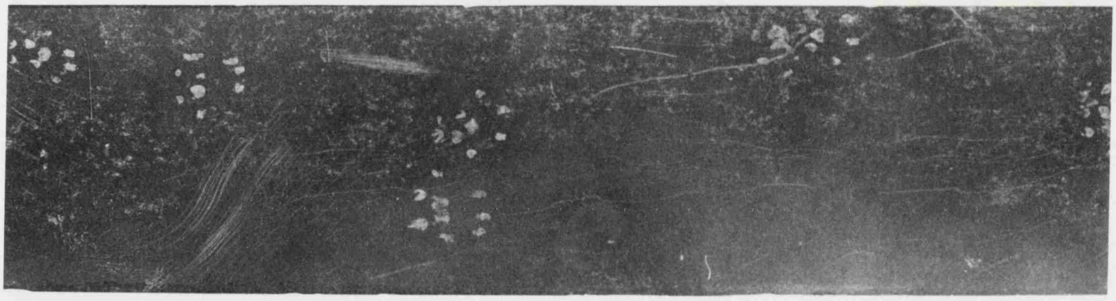
B. R. RATTUS FOOTPRINTS ON SMOKED PAPER STRIPS

TOP: Level surface slow walk
BOTTOM: Level surface rapid walk



A





B

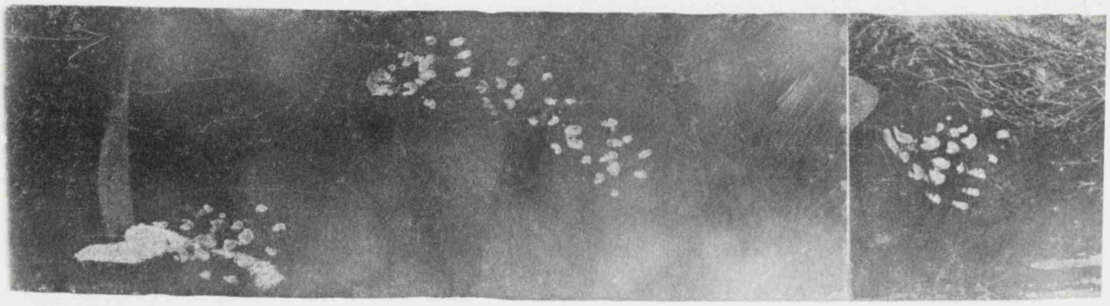


Table 2.3 TRAP AVOIDANCE BEHAVIOUR IN COCOA, WAIMARO RESEARCH STATION, VITI LEVU

Date	Number of trap nights	Number of traps visited	Number of traps not visited	Number of rats trapped	
				R. rattus	*R. exulans*
Oct. 1970	42	28	14	1	0
Nov. 1970	73	62	11	1	1
Feb. 1971	65	56	9	0	0
Mar. 1971	30	22	8	3	2
May 1971	85	74	11	7	5
June 1971	64	33	31	1	0
Totals	359	275	84	13	8
Percentage visited		76.6			
Percentage not visited			22.4		
Percentage visited that caught rats				7.6	

R. exulans. It was also assumed that the visit to capture ratio was not noteably increased by a few animals visiting a number of traps during a single night. Thus the conclusion was that R. rattus exhibited marked trap avoidance at Waimaro.

During the three years of trapping at Waimaro 75 R. rattus were caught and only 12 of these animals (16 percent) were recaptured and each of those on only one occasion. This contrasted with the 35.5 percent of R. exulans that were recaptured at least once at Salt Lake. Also of note, because it reflected avoidance behaviour, was the distribution of R. rattus captures over the three days of trapping each month. Again in contrast to R. exulans (Figure 2.16B), 22.7, 28.0 and 49.3 percent of all R. rattus first captures occurred on the first, second and third day respectively. The differences in capture rate between wire and break-back traps in palm crowns (Table 2.2B) suggested that R. rattus avoided cage traps in particular but not all trap types. This species may have been unwilling to enter confined spaces or wished to avoid metal objects introduced into the habitat. The small size and predominantly wooden construction of the break-back traps may not have represented such an intrusion.

Whatever the reason for the difference in capture-rate, it is evident that break-back trapping gives the best indication of relative numbers and distribution of R. rattus.

2.4B MOVEMENT PATTERNS IN COCONUT AND COCOA PLANTATIONS

I. Objectives and methods

The prime objective in investigating Rattus movement in the two crops was to attempt to provide a rational basis for the spacing of bait stations during control programmes. Previously, the spacing of poison baits in tropical tree crops appears to have been on an arbitrary basis with some authors

(Smith, 1969; Friend, 1971) giving no rationale for the spacing adopted.

Grid trapping, with marking and release, was established primarily to estimate population numbers and this technique also provided a basis for estimating population movements. This is probably the most widely used method for estimating movement, but it has some shortcomings; one of which is the effect that trap spacing has on the distance moved. Hayne(1950) and Stickel (1954) have shown that traps set too closely lead to underestimates of distances, while those set too widely tend to give overestimates. Blair (1951) considered that the most serious disadvantage of the grid trapping method was that it prevents all further movements until the animals are released. However, the relative importance of these disadvantages depends on the methods used to express movement and the ultimate objectives of the investigation.

Two linear measures have been used to evaluate movement in the present study, the first being the 'Adjusted Range Length' (A.R.L.) of Stickel (1959). Briefly, A.R.L. is the straight line distance between the most widely separated sites of capture for an individual rodent, with a correction factor of one half the distance to the next nearest trap added to each end. While Stickel's measure gives an estimate of the amount of terrain a rat ranges over in a life-time, particularly when captured a number of times Brant's (1962) 'average distance' (Av. D.) measure is a better estimate of distance within a particular time span. In this second method the mean distance moved between captures is derived by dividing the sum of all the distances moved by the number of times caught. A rat captured in the same trap as previously registers zero distance moved and this is included with the other data.

An advantage of these linear measures was that they were not as susceptible, as areal estimates of movement, to the biases that grids generate. It was therefore not necessary to apply correction factors such as proposed by Watts (1970), particularly as the aim of investigating movement in the present study was to establish approximate distances moved over the relatively short period of a month.

II. Results and Discussions

a) Movement in coconut groves. As very few recaptures of R. rattus occurred at Salt Lake all assessment of movement was confined to R. exulans which was abundant throughout the site during the 34 months of the survey (Section 2.5C).

Using a computer programme, the A.R.L.s' and the Av.Ds' were calculated for all captures of males and females. For the A.R.L., it was further subdivided according to the number of times an animal was captured, while Av.D. was calculated for juvenile, sub-adult and adult animals both within and between trapping periods. The age classification was based on animal weight, those under 30 g classified as juvenile (most being non-perforate females and non-scrotal males), those from 30-39 g as sub-adults (a few being non-perforate and non-scrotal), while those 40 g or heavier were considered to be adult.

The A.R.L. for both sexes increased with the number of times an animal was captured and there was little difference between the sexes in the lower capture categories (Figure 2.20A). For males, the A.R.L. appeared to level off when there were more than seven recaptures, suggesting that the limits of the male A.R.L. had been reached. The female population showed the same trend but with no increase in A.R.L.'s after five recaptures. The need for several recaptures to establish a

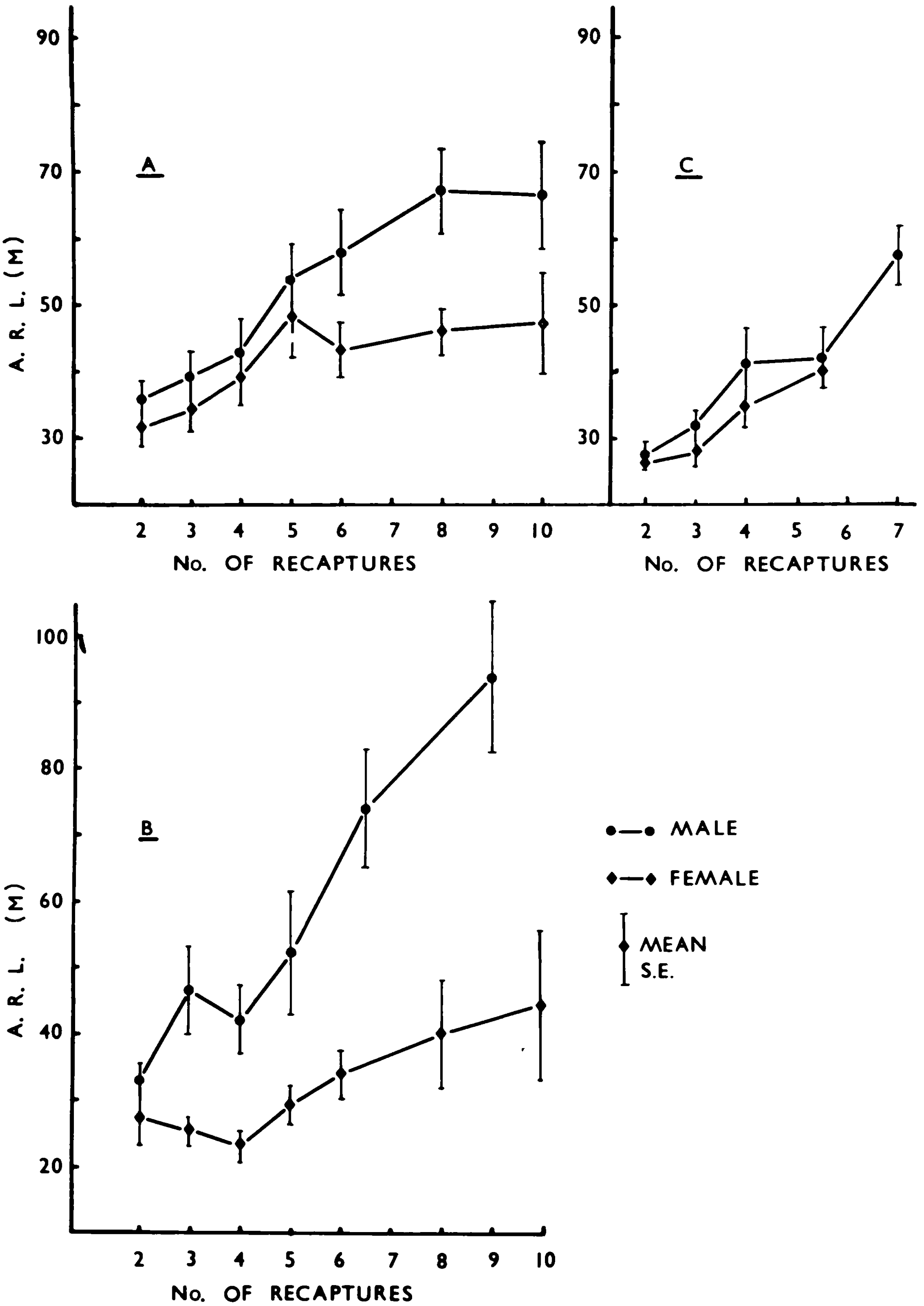
FIGURE 2.20

THE EFFECT OF CAPTURE FREQUENCY ON THE CALCULATED AVERAGE RANGE LENGTH (A.R.L) FOR R. EXULANS

A. Salt Lake coconut area

B. Namara Road cocoa plot

C. Grenada Cocoa plot, Wainigata Research Station


A
C
B
A. R. L. (M)
No. OF RECAPTURES
MALE
FEMALE
MEAN
S.E.

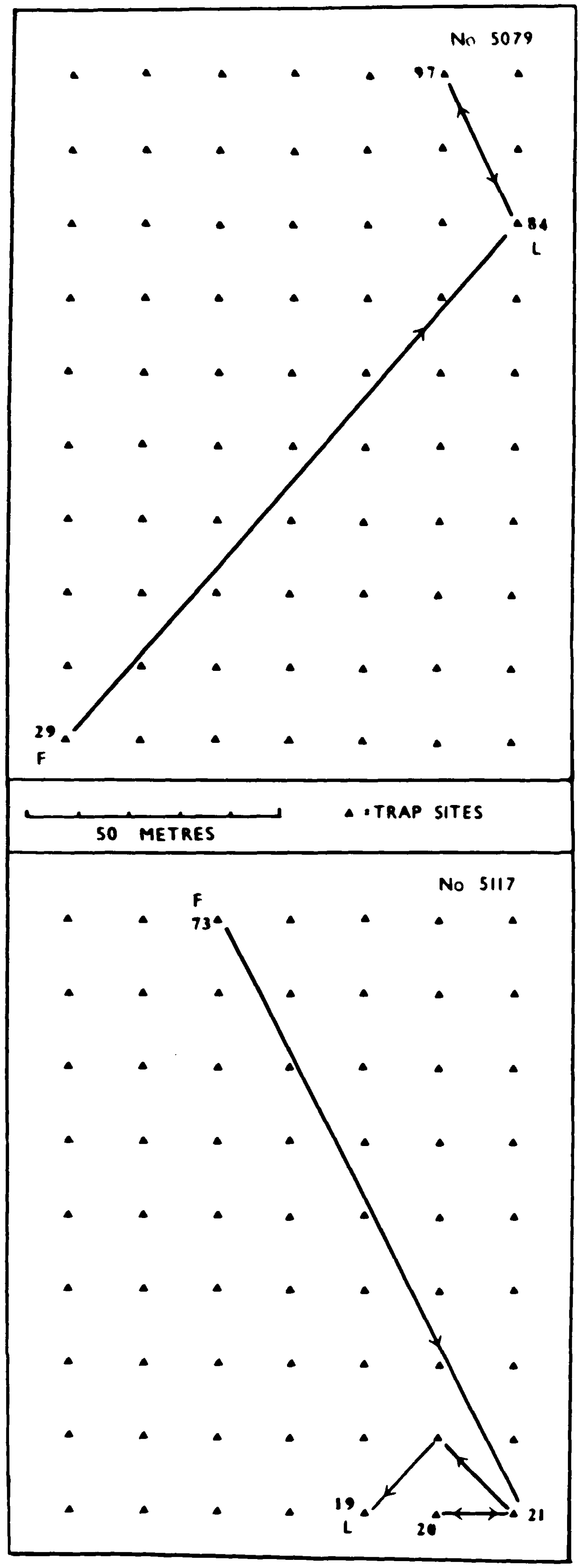
species' maximum movements was clearly evident from these data and several workers have previously attempted to determine what constitutes an adequate sample size when determining range lengths. Godfrey (1954) in his study of Microtus, found that after 10 recordings per vole no further increases occurred in the distance between the two most widely separated points of location. He concluded that the number of recordings were more important than their distribution in time when the limits of the range were being determined in a species such as Microtus which moves over a restricted area. Fitch (1958), in a study of vertebrate movement in Kansas, considered that averages based on seven or more points were sufficiently representative. Brant (1962) used a method for Peromyscus and Reithrodontomys similar to that employed for the results shown in Figure 2.20 and also found that the maximum distance moved levelled off in both species after eight or more recaptures in males and after five to six in females.

R. exulans males moved significantly ($t = 2.0$, $p > 0.05$) greater distances than females during their lifetimes, with A.R.L.s for all adults captured five or more times being 62.2 metres in males and 53.3 metres in females. Females were possibly restricted in their movements by the necessity to remain in close proximity to the nest site during advanced pregnancy and while feeding a litter, whereas males were free to move at all times. Some of the differences between males and females could also have been due to the tendency for young males to move considerably distances before establishing a home range area (Figure 2.21). The movement between the main Salt Lake grid and the check lines 50-80 m beyond the grid boundaries (Figure 2.2) highlighted this behaviour.

FIGURE 2.21

HOME RANGE MAPS OF R. EXULANS MALES SHOWING LONG DISTANCE MOVEMENTS THAT OCCURRED AS JUVENILES.

Trap sites are numbered as per Figure 2.2. and direction of movement between successive captures indicated by the arrows. Number 5079 remained in the population from February to October 1970 and was caught six times. The long move from site 29 to 84 was made between February and May. Number 5117 remained in the population from June 1970 until 1971 and was caught seven times. The long move was made between June and July 1970. F = site first caught, L = site last caught.


No 5079
97
84
L
29
F
50 METRES
▲ : TRAP SITES
No 5117
F
73
19
L
20
21

During the 31 trapping periods, when over 800 animals were marked, 23 males moved from the grid to line areas, or visa versa, while only four females made similar moves.

Average distances between captures were significantly lower (p = >0.05 in all cases) for juvenile and sub-adult animals, both within and between trapping periods (Table 2.4). This was not unexpected as such individuals would be in the process of establishing a home area and, by the time they were moving greater distances between captures, would have reached a weight that classified them as adults.

The Av.D.s between trapping periods were considerably greater

Table 2.4 AVERAGE DISTANCE MOVED BY *RATTUS EXULANS* IN THE SALT LAKE COCONUT PLANTATION; WITHIN A TRAPPING PERIOD OF 3 DAYS AND BETWEEN TRAPPING PERIODS OF ONE MONTH

Within a Trapping Period.

		No. animal captures	Av.D. (m)	S.E.
Juvenile	Male	41	7.5	1.7
	Female	45	7.6	1.5
Sub-Adult	Male	66	6.5	1.1
	Female	103	7.5	1.9
Adult	Male	333	12.8	1.3
	Female	292	9.4	0.9

Between Trapping Periods

		No. animal captures	Av.D.	S.E.
Juvenile	Male	73	14.8	1.9
	Female	83	20.6	2.4
Sub-Adult	Male	110	14.5	1.3
	Female	159	13.9	3.7
Adult	Male	332	23.7	1.5
	Female	342	19.0	1.3

than those within trapping periods, which is what would be expected as animals had at least 30 days in which to move about within their home range, thereby increasing the chance of being caught at a site some distance from the previous month's capture. Conversely, Av.D.s within a trapping period were probably shorter because there was less time for animals to move significant distances. Certainly the number of adult recaptures within and between periods were similar, suggesting that there was no overall behavioural difference in trap response resulting from one day as opposed to 30 days between trap exposures.

As might be expected there were significant differences in Av.D. between sexes ($p = > 0.01$ in both cases) with males moving further than females. This feature of R. exulans movement, whether measured by A.R.L. or Av.D., was common to several small rodents, having been reported by Brant (1962) for Peromyscus and Reithrodontomys, by Jackson and Strecker (1962) for Rattus rattus and by Tomich (1970) for Mus musculus.

b) Movement in cocoa groves. As few recaptures of R. rattus occurred at the Grenada and Namara sites, data on movement in these areas was confined to R. exulans. However, in the absence of significant numbers at the Waimaro sites, of either R. exulans or R. norvegicus, the 49 recaptures of R. rattus permitted a limited assessment of this species' movement.

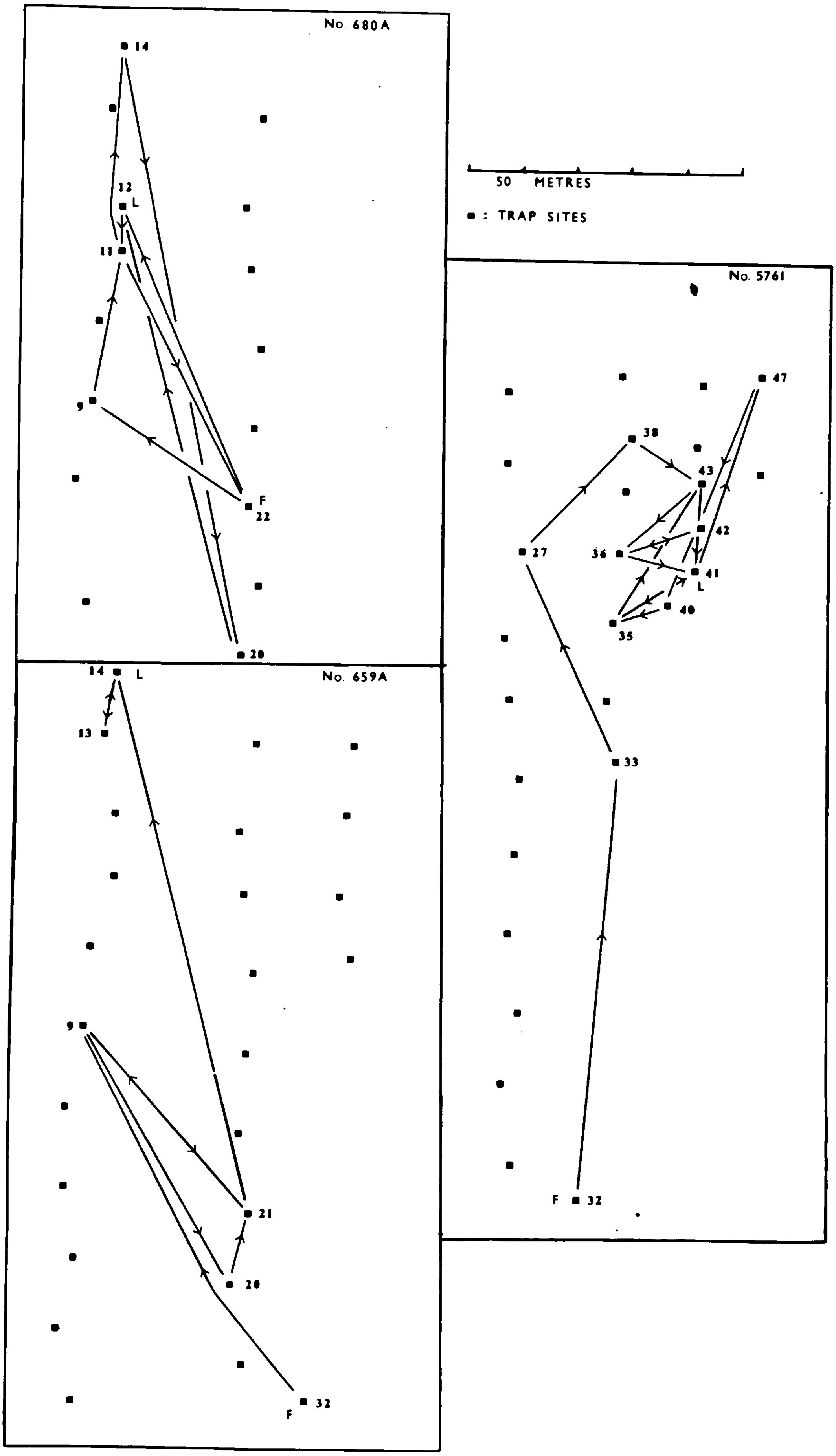
At Namara and Grenada sites, A.R.L.s for R. exulans exhibited trends similar to those of the Salt Lake population (Figure 2.20B and C). A general increase in A.R.L. occurred with increasing numbers of captures, with that of the female A.R.L.s tending to level off with fewer recaptures. However at neither site were there sufficient recaptures to allow the upper limit of male A.R.L.s to be determined. Of particular note was the very marked difference

FIGURE 2.22

HOME RANGE MAPS FOR THREE R. EXULANS AT THE NAMARA ROAD COCOA PLOT, SHOWING

THE EXTENT OF THE AREA OCCUPIED AS WELL AS HOME RANGE SHIFTS

Trap sites are numbered as per Figure 2.6 and the direction of movement between successive captures indicated by the arrows.
All rats (males) were first captured as juveniles.
Numbers 659A and 680A remained in the population between July and December 1971 while occupying relatively large home ranges. Number 5761 was first caught in June 1971 but moved as far as site 27 by July to remain in that area until January 1972
F = site first caught, L = site last caught.



No. 680A
14
12
L
11
9
F
22
20
50 METRES
■ : TRAP SITES
No. 5761
47
38
43
42
36
27
41
L
40
35
33
F
32
No. 659A
14
L
13
9
21
20
F
32

between the A.R.L.s of males and females at Namara (Figure 2.20B) with males clearly moving significantly greater distances at almost all capture frequencies. A possible explanation for this difference lies in the relatively high population densities (110 to 210 per hectare) prevailing at this site throughout the survey period (June 1971 to September 1972). This contrasted with the Grenada and Salt Lake sites which had densities ranging from 30 to 80 and 25 to 75 per hectare respectively. In habitats with a high population considerably more interspecific fighting might have taken place as a result of competition for available resources which, particularly in the case of males, would have caused wide ranging movements and possibly more frequent home shifts. Certainly some males at Namara were ranging over a considerable area (Figure 2.22) while others made noteable home range shifts.

Female A.R.L.s were similar at Namara and Grenada sites with an apparent upper limit of approximately 40 m, while the maximum female A.R.L. at Salt Lake was about 45 m. This indicated considerable uniformity of behaviour in the different habitats.

The average distances moved at Namara and Grenada, both within and between trapping periods, again showed the same trends apparent at Salt Lake. At both sites, a general increase in the distance moved took place with increasing age, and significant differences ($p = > 0.05$ in all cases) were observed at both sites, in terms of adult movements within and between periods (Tables 2.5 and 2.6).

More marked differences between male and female movements were recorded at these two cocoa sites particularly in the 'between trapping' results. In addition, male Av.D.s at Namara, within and between periods, were significantly greater ($p = > 0.05$ in all cases) than the corresponsing distances at the Grenada site, a facet of behaviour possibly due to differences in population densities (Section 2.5C).

Table 2.5 AVERAGE DISTANCE MOVED BY RATTUS EXULANS IN THE GRENADA COCOA PLANTATION, WAINIGATA, VANUA LEVU, WITHIN A TRAPPING PERIOD OF 4 DAYS AND BETWEEN TRAPPING PERIODS OF ONE TO THREE MONTHS.

Within a Trapping Period

		No. animal captures	Av.D. (m)	S.E.
Juvenile	Male	6	7.0	3.2
	Female	2	18.8	-
Sub-Adult	Male	13	3.8	1.5
	Female	14	10.7	2.9
Adult	Male	151	12.3	1.0
	Female	101	9.3	1.0

Between Trapping Periods

		No. animal captures	Av.D. (m)	S.E.
Juvenile	Male	6	7.2	2.7
	Female	2	19.2	-
Sub-Adult	Male	15	4.2	1.7
	Female	18	10.7	2.7
Adult	Male	78	20.3	1.8
	Female	69	12.1	1.2

Table 2.6 AVERAGE DISTANCE MOVED BY RATTUS EXULANS IN AN OVER-GROWN COCOA PLANTATION, NAMARA ROAD, VITI LEVU, WITHIN A TRAPPING PERIOD OF 3 DAYS AND BETWEEN TRAPPING PERIODS OF ONE MONTH

Within a Trapping Period

		No. animals captures	Av.D. (m)	S.E.
Juvenile	Male	8	7.7	3.9
	Female	10	6.2	4.7
Sub-Adult	Male	23	1.3	0.7
	Female	34	5.3	1.3
Adult	Male	176	18.7	2.0
	Female	175	5.9	1.0

Between Trapping Periods

		No. animal captures	Av.D. (m)	S.E.
Juvenile	Male	26	6.6	3.1
	Female	24	7.3	2.4
Sub-Adult	Male	39	21.2	5.9
	Female	65	9.4	1.6
Adult	Male	217	26.2	1.6
	Female	233	8.6	1.2

At the Waimaro site, 49 recaptures of R. rattus occurred between April 1970 and April 1972 in contrast to only 11 recaptures of both R. exulans and R. norvegicus. Even though no R. rattus were recaptured more than three times it was feasible to derive A.R.L.s and Av.D.s . The A.R.L. for both sexes of R. rattus captured two or three times was:-

	Number of Animals	A.R.L. (m)	S.E.
Male	23	39.8	4.8
Female	20	38.3	3.8

These A.R.L.s,when compared with Figure 2.20, suggested that R. rattus ranged over greater distances than R. exulans. However, the upper limit for R. rattus could only be postulated using R. exulans data as a guide. At the Salt Lake, Grenada and Namara sites, R. exulans A.R.L.s derived from two or three captures increased approximately 1.5 times for females and 2.0 times for males to reach their apparent maximum levels (Figure 2.20). Using this criterion R. rattus males and females would have maximum A.R.L.s of approximately 80 and 60 m respectively.

Since the Av.D. within a trapping period could only be based on eight recaptures of both sexes, the derived distance (15 $\pm$ 3.8 m) was an approximation. However, 41 recaptures between periods gave a better measure of Av.D., 25.8 $\pm$ 2.7 m , but it should be noted that this figure was for both sexes and included movements by juveniles as well as adults. Because the inclusion of juvenile movements would, as the data for R. exulans illustrated (Tables 2.4 - 2.6), clearly reduce the derived Av.D. value, a true Av.D. for adult R. rattus over a one month period in cocoa plantings would undoubtedly be higher.

III. Summary of Rattus movement

Tomich (1970), reporting on the results of a 10 year study of rodents (Mus musculus, R. exulans, R. rattus and R. norvegicus) in Hawaii, using the techniques discussed, recorded movements that tended to be longer than those revealed by the present study. Maximum A.R.L.s for R. exulans males ranged from 67 m in gulches to 100 m in cane fields while the respective values for females were from 48 to 96 m. Av.D.s for R. exulans over a four day trapping period ranged from 18 m in gulches to 29 m in cane-fields for males and 13 m to 26 m for females. R. rattus A.R.L.s showed the same trends (males 62 m in gulches and 81 m in fields; females 53 and 82 m respectively) but with females tending to travel as far as males in the cane-field habitat, a feature also apparent in the Av.D.s for this species (males 16 m in gulches, 35 m in fields; females 11 m and 37 m respectively).

It thus appears that habitat plays an important part in governing a species area of activity and it seems that ranges are restricted in diverse habitats such as Hawaiian gulches and in coconut and cocoa groves where there is considerable ground cover. This factor must therefore be taken into account when deciding on bait spacing in a particular crop. However, little is known about the effects of the distance between bait stations. Chitty and Southern (1954) have suggested the presence of at least one station within the normal foraging range of each rat, a distance that will clearly vary greatly. Barbehenn (1962), working with a mixed Rattus population in the Marshall Islands, found that very few animals moved more than 30 m to feed at bait stations in areas with good ground cover and that there was a lapse of several days before all animals within this distance started to feed.

As bait preparations tend to deteriorate rapidly in tropical field crops, particularly in areas of high rainfall, it is desirable that most of the rat population start feeding as soon as the material is laid. Thus, several bait sites should be placed within the immediate range of all animals and, in view of Barbehenns's findings, these should be spaced within the limits indicated during the present study by the adult Av.D. values for within trapping periods. If these are considered to be minimum distances they indicate bait spacings of 21.6 to 25.0 m i.e. double the mean Av.D.'s for adult R. exulans. Since only eight R. rattus were caught within a trapping period this proposed spacing is based on the Av.D.s for R. exulans alone.

As there was no data indicating a better basis for bait spacing, these Av.D.s were used to govern bait density in the rat control trials in cocoa, the lower and higher figures representing approximately 22 and 16 sites per hectare respectively (Section 5.4).

2.4C THE VERTICAL SEPARATION OF SPECIES

Several authors (Strecker, 1962; Baker, 1946 and Fall et al. 1971) have discussed the apparent vertical separation of R. exulans and R. rattus in coconut groves and generally concluded that R. rattus is predominant in the crown habitat and is responsible for most of the damage to coconuts. This conclusion was drawn from habitats where both species were present and therefore possibly actively competing for the crown component. In the absence of R. rattus in the Tokelau Islands (Wodzicki, 1969), R. exulans climbs palms and damages varying numbers of developing coconuts. However McCartney (1970) found that on Eniwetok Atoll, Marshall Islands, R. exulans, in the apparent absence of R. rattus did not climb above approximately six metres, a height that encompassed the crowns of shorter but not the more vigorous mature palms. This suggests that R. exulans arboreal activity is confined, for some behavioural reason, to low elevations within any habitat and therefore coconuts are only attacked when palm crowns are within the species' apparently restricted vertical range. Such a feature of R. exulans behaviour could explain the presence of damaged coconuts in the Tokelau Islands as the typically impoverished atoll soil, together with the high density of palms in the groves, results in the presence of many short palms.

Arboreal Activity

To investigate arboreal activity in Fiji, trapping (break-back and cage) was carried out in palm crowns and the first jorquette of cocoa trees during the major population studies. In addition, simultaneous break-back trapping of ground and palm crowns was carried out during 1972 at a series of randomly chosen sites on south-east Vanua Levu. Traps were laid on three consecutive nights, two being placed in each of 10 palm crowns while an additional 10-15 traps were located in a ground line in the same area. Nine sites were trapped in this manner and while R. exulans was caught in all ground lines, none were captured in palm crowns (Table 2.7). In marked contrast, R. rattus was trapped in crowns at all sites but the ground at only two locations. Of the 90 palm crowns trapped, 48 percent yielded rats, a relatively high level of occupancy that bore little relationship to the amount of damage present (Section 3.2).

Crown and ground break-back trapping in the Salt Lake study area at the conclusion of cage trapping also indicated a vertical separation of species. In 336 trap nights, 12 R. rattus and two R. exulans were caught in palm crowns while 630 trap nights on the ground yielded six R. rattus and 69 R. exulans. Crown trapping with cage traps was also carried out at Salt Lake and, although 12 R. rattus were caught on 414 trapping nights, the known trap avoidance behaviour of this species precluded this data being used as a valid indicator of vertical separation of the two species. However, in the 414 trap nights, eight R. exulans

Table 2.7 VERTICAL DISTRIBUTION OF <u>RATTUS RATTUS</u> AND <u>RATTUS EXULANS</u> IN COCONUT PLANTATIONS ON VANUA LEVU

Site	Palm Height (m)	Ground Traps			Crown Traps			No. palms rats caught
		Trap nights	*Rattus exulans*	*Rattus rattus*	Trap nights	*Rattus exulans*	*Rattus rattus*	
Benau	10-14	78	8	0	60	0	2	1
Naliba	8-10	39	7	0	60	0	3	3
Natakea	10-12	33	4	0	60	0	10	6
Naleba	10-14	30	1	1	60	0	10	6
Nacavinadi	10-14	33	4	0	60	0	17	9
Natakea A	10-12	24	5	0	60	0	10	6
Natakea B	10-12	21	6	1	60	0	6	5
Korosi	10-12	21	5	0	48	0	5	3
Tabia	10-12	27	5	0	48	0	7	4
Totals		306	45	2	506	0	70	43
Rats/100 trap nights			14.7	0.7		0	13.8	
Percentage of palms trapped occupied by rats								48

were caught in palm crowns, with three of these individuals being recaptured in the same month, two in crowns and the third at a ground site. The presence of R. exulans in palm crowns at Salt Lake was almost certainly related to palm height, for all animals were caught in the shortest palms in the area which were only 3.5 to 5.0 m high, whereas the majority of palms in this region were between 7.5 and 9.0 m.

Trapping in the cocoa areas also indicated that R. exulans had a vertical component in its home range and confirmed the preference of R. rattus for foraging in the arboreal component of a habitat (Table 2.8). Traps placed in the first fork of the average mature cocoa tree were seldom higher than two metres

Table 2.8 CAPTURE SITES OF THREE RATTUS SPECIES IN COCOA (CAGE TRAPPING DATA INCLUDES ORIGINAL AND RECAPTURES).

Cocoa Area	Sites Caught					
	R. exulans		R. rattus		R.norvegicus	
	Ground	Tree	Ground	Tree	Ground	Tree
Waimaro	27	15	64	119	42	7
Namara	850	825	20	35	2	0
Total	877	840	84	154	44	7
Percentage of total	51	49	35	65	86	14

and in most cases only 1.0 to 1.5 m above the ground. At these heights almost as many R. exulans were caught in the trees as on the ground, clearly indicating extensive use of the lower portion of the arboreal range.

While trapping results from cocoa and coconut plantations suggested that R. exulans favoured low elevations, as was also found by McCartney (1970), such data did not exclude the possibility of some competition between the two arboreal Rattus species for at least the higher part of the vertical range. It was postulated that during an extended period of crown break-back trapping the resident R. rattus population would be depleted and thus permit R. exulans, if they were being excluded by R. rattus, to extend their range vertically and occupy the crowns of taller palms. Therefore, in the latter part of the trapping period some R. exulans captures could be expected in the palm crowns.

To investigate this aspect , four break-back traps were set in the crowns of a line of 20 mature bearing palms that extended through a typical plantation where the average palm height was 12 m. Trapping was carried out for 10 days and captures were as follows:

Day	1	2	3	4	5	6	7	8	9	10
Catch	2	1	1	3	1	0	0	1	0	0

(R. rattus only)

No R. exulans were caught at any stage during the 10 days despite the apparent removal of most R. rattus by the fifth day. A ground trap line of 20 traps was run on the 11th day resulting in the capture of seven R. exulans thereby indicating a ground population of this species remained. While this crown removal trial was not repeated on short palms, the above results suggested that R. exulans was not being excluded from tall palms by the presence of R. rattus, a conclusion in support of Whelan and Whelan (1971) who reported trapping both species in the crowns of short palms in the same night.

While R. rattus was most frequently trapped in palm crowns and even in the first jorquette of cocoa trees, inspection of palm crowns during daylight suggested they were part of the ground Rattus population which, because of the preference for arboreal foraging were more likely to be caught in trees and conversely less likely to be trapped on the ground. During 1971 and 1972, regular crown inspections were carried out on 60 survey palms at Salt Lake with a total of 291 inspections during the two years. Two R. exulans and four R. rattus were located on only four occasions and in three different palms, a result contrasting with those for crown trapping on the same 60 palms; i.e. 24 R. rattus and 10 R. exulans in 17 different palms within six months. The absence of both species during the day clearly indicated that most animals had home ranges based on the ground, with the population separating at night and R. rattus moving to greater heights than R. exulans. Palm crowns were therefore an extension of the ground habitat which both species utilised if the crowns were within the apparent species' specific height range. Thus, in areas of short palms, both species would move into the crowns at night, while the tops of tall palms would only be visited by R. rattus. Furthermore, R. rattus did not appear to be excluding R. exulans from sites within the latter's normal arboreal range.

2.5 POPULATION STUDIES

2.5A AGE STRUCTURE

I. Objectives and methods

Despite a wealth of data on wild Rattus species, particularly in temperate countries, little appears to be known about the age structure of natural populations of the genus.

As R. exulans was the most abundant species in Fiji, and the indigenous rat of the Pacific, an attempt was made to determine the age of individuals utilising the weight of the dried eye lens, a method pioneered by Lord (1959), using the cottontail rabbit (Sylvilgus floridanus). It was hoped that the method would prove accurate enough to enable a total population sample to be divided into sufficient age categories to permit a time-specific (or vertical) life-table to be constructed (Southwood, 1966).

Since Lord (1959) showed that data for the dry weight of the eye lens could be used to determine the age composition of populations of cottontail rabbits a number of other investigators have studied this relationship for numerous species. Friend (1967a) has reviewed 33 studies and has discussed variables inherent in evaluating lens-weight data as a criterion of age.

The weight of an eye lens increases along an asymptotic curve, throughout the normal lifespan of many mammals. In rats (laboratory R. norvegicus) this increase in lens weight has been found to be independent of the nutritional status of the animals, with rats maintained under several controlled diet conditions failing to produce differences in lens weights despite nearly two-fold differences in body weight (Friend, 1967b). In contrast, Friend and Severingaus (1967) found, during field investigations of white-tailed deer in New York State, that there were significant differences in both lens weight and body weight of deer of the same age but from ranges of poor and good nutritional status. The differences in lens weight were thought to be the result of nutritional stress that occurred before the deer was born, or before weaning, because nutritional deficiencies were most apparent during these periods. These findings do not conflict with Friend's (1967b) laboratory studies since the animals on which Friend based his work were all the progeny of well nourished parents and experimental procedures were not begun until after weaning. Thus while post weaning differences in nutritional status do not influence rat eye lens weights it is evident that nutrition during pregnancy and lactation should be considered a source of variation even though little quantitative data on this aspect has been accumulated.

The lenses used to investigate the age structure of R. exulans were collected during grid trappings at Wainigata Research Station. All animals were collected from the trap-lines before 0900 hours each morning and placed in a refrigerator until dissected later in the day. Early collection and maintenance at a low temperature was essential for Rongstad (1966) found that cottontail rabbit lenses deteriorated beyond use in less than 12 hours at temperatures as high as 37°C.

Following the method of Lord (1959) eyes were removed and placed, in their pairs, in a vial of fixative consisting of 10 percent buffered formalin. After 20-30 days lenses were removed from the eyes and dried in a hot air oven at 80°C for 48 hours. After drying lenses were cooled in a dessicator and then weighed, in pairs, to the nearest 0.1 mg. A drying time of 48 hours was sufficient to give constant dry weights on repeated washings.

Friend (1967c) reported that after four weeks fixation in formalin there was a significant increase in the lens weight of laboratory rats. During the present study fixing times of 20 and 120 days were compared by assigning one lens from each rat to each treatment, after establishing there was no significant differences between the weight of right (mean = 12.07 $\pm$ 0.18 mg n = 46) and left lenses (mean = 10.04 $\pm$ 0.20 mg n=46) weighing between 10.0 and 14.0 mg. There was no significant difference between the weight of lenses fixed for 20 days (mean = 12.68 $\pm$ 0.26 mg n = 30) and 120 days (mean = 12.66 $\pm$ 0.26 mg n = 30), therefore fixing time was not considered a source of variation.

To age the field collected lenses it was necessary to obtain lenses from R. exulans of known age, therefore rats were bred in captivity at Koronivia Research Station. The cage population was started by trapping pregnant females in the field but later litters were obtained from pairs mated in captivity. Over a period of two years it was possible to remove 46 animals, aged 7 to 484 days, from the cage population. All such animals were killed and the lenses treated in the same manner as those collected in the field.

To establish the relationship between lens weight and age a line was fitted to the plotted lens weights by Connolly, Dudizinski and Longhurst's (1969) method of calculating a linear regression equation from $\log_{10}$ of the lens weight, and the reciprocal of the age plus a constant. Connolly et al. used the value 53 (i.e. age + 53) as the constant and derived this by computer iteration. The same approach was used to determine which value gave the best fit for R. exulans data. Values from 20 to 80 were tested for linearity of regression and the value 59 was found to give the best fit ($r = -0.9819$).

The statistical advantages resulting from the transformation of lens weights into logs of lens weights, and ages into the inverse relationship $\frac{1}{\text{age} + 59}$, have been described by Dudzinski and Mykytowycz (1961). These transformations make the model linear and eliminate the heterogeneity of array variances (result of lens weight variability increasing with age) which is characteristic of the untransformed data. The calculation of the regression is considerably simplified by conversion to a reciprocal and confidence limits can be more easily determined.

II. Results and Discussion

Lens weights and ages of 46 known age R. exulans are shown in Table 2.9. All weights are the total for both lenses and data for male and female have been combined for all calculations because there was no significant sexual differences in lens weights (mean male = 11.36 $\pm$ 0.38 mg/lens, n = 33; female = 11.46 $\pm$ 0.44 mg/lens, n = 33). This result agrees with the findings of Martinet (1966) for Microtus arvalis and Östbye and Semb-Johansson (1970) for the Norwegian lemming (Lemmus lemmus).

Table 2.9 EYE LENS WEIGHTS OF 46 KNOWN AGE R. EXULANS

RAISED IN CAGES AT KORONIVIA RESEARCH STATION

Sex	Weight of lens pair (mg)	Age (days)	Sex	Weight of lens pair (mg)	Age (days)
M	9.6	7	F	25.4	335
F	10.6	11	F	25.8	253
F	12.6	20	F	26.0	382
F	14.5	30	M	26.5	370
M	15.5	32	M	26.7	391
M	16.6	52	F	26.7	294
F	17.0	56	F	27.0	358
F	17.7	92	F	27.0	283
M	19.7	92	F	27.1	332
F	20.0	113	M	27.3	263
M	20.3	87	M	28.2	331
F	20.4	92	F	28.4	411
F	20.8	87	M	28.6	391
F	21.1	134	M	28.8	256
M	21.5	113	M	28.9	475
F	21.8	134	F	29.2	350
F	22.4	115	F	29.3	391
M	23.7	134	F	29.4	343
M	23.7	190	M	30.4	353
F	23.9	246	M	30.6	484
F	23.9	246	M	30.8	419
F	24.0	190	F	31.4	427
F	25.3	249	F	31.4	475

The regression equation describing the relationship between lens weight and age was Y = 4.2659 - 2.7735 X which was calculated with 95 percent confidence limits. (Figure 2.23). The data was also plotted in the original form (Figure 2.24) with the regression line and confidence limits superimposed after being transformed from the data shown in Figure 2.23.

From Figure 2.24 it is obvious that the precision of age estimates based upon lens weight, decreases rapidly with increasing age. For example the 95 percent limits of an estimate for an animal with a lens weight of 20 mg ranges from 67-132 days, while at 24 mg the range is 115-270 days (Table 2.10).

Table 2.10 CONFIDENCE INTERVALS FOR VARIOUS AGES OF *R.EXULANS* BASED ON THE REGRESSION EQUATION AND VARIANCES OBTAINED FROM CAGE REARED ANIMALS AGED UP TO 484 DAYS

Lens weight (mg)	Estimated age (days)	95 percent confidence limits (days)
10	8	5 - 15
15	42	29 - 57
17	58	42 - 80
20	92	67 - 132
24	169	116 - 270
26	246	157 - 460
28	350	204 - 856

It was evident from this analysis that eye lens weight was a useful indicator of age for *R. exulans* only if animals were less than three months old. Over such an age lens weight increased slowly and variation between individuals became much greater.

FIGURE 2.23

EYE LENS WEIGHT-AGE RELATIONSHIP FOR 46 KNOWN AGE *R. EXULANS*

The solid line corresponds to the equation $y = 4.2659-2.7735X$.
Dotted lines denote 95 percent confidence limits for age estimation.

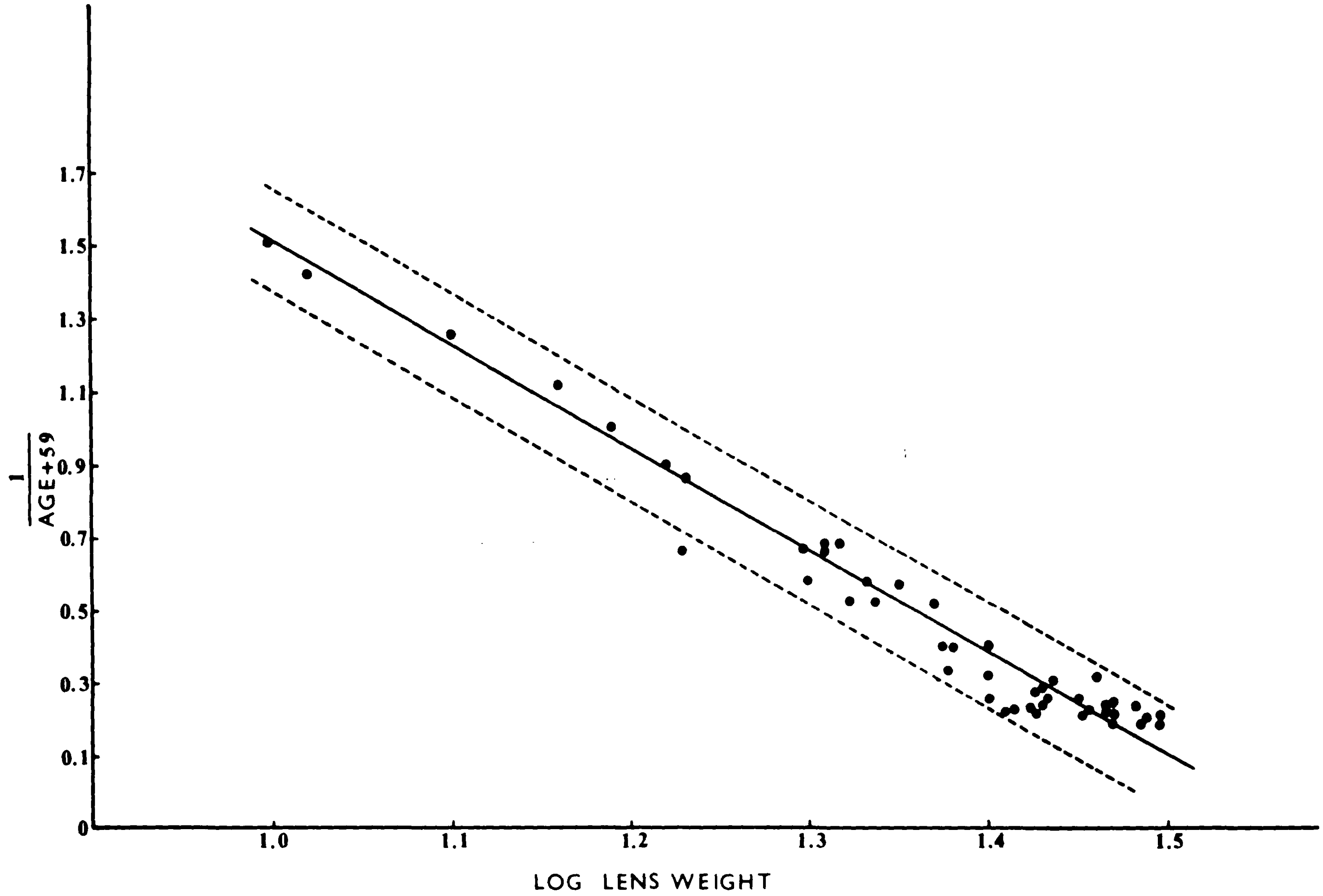
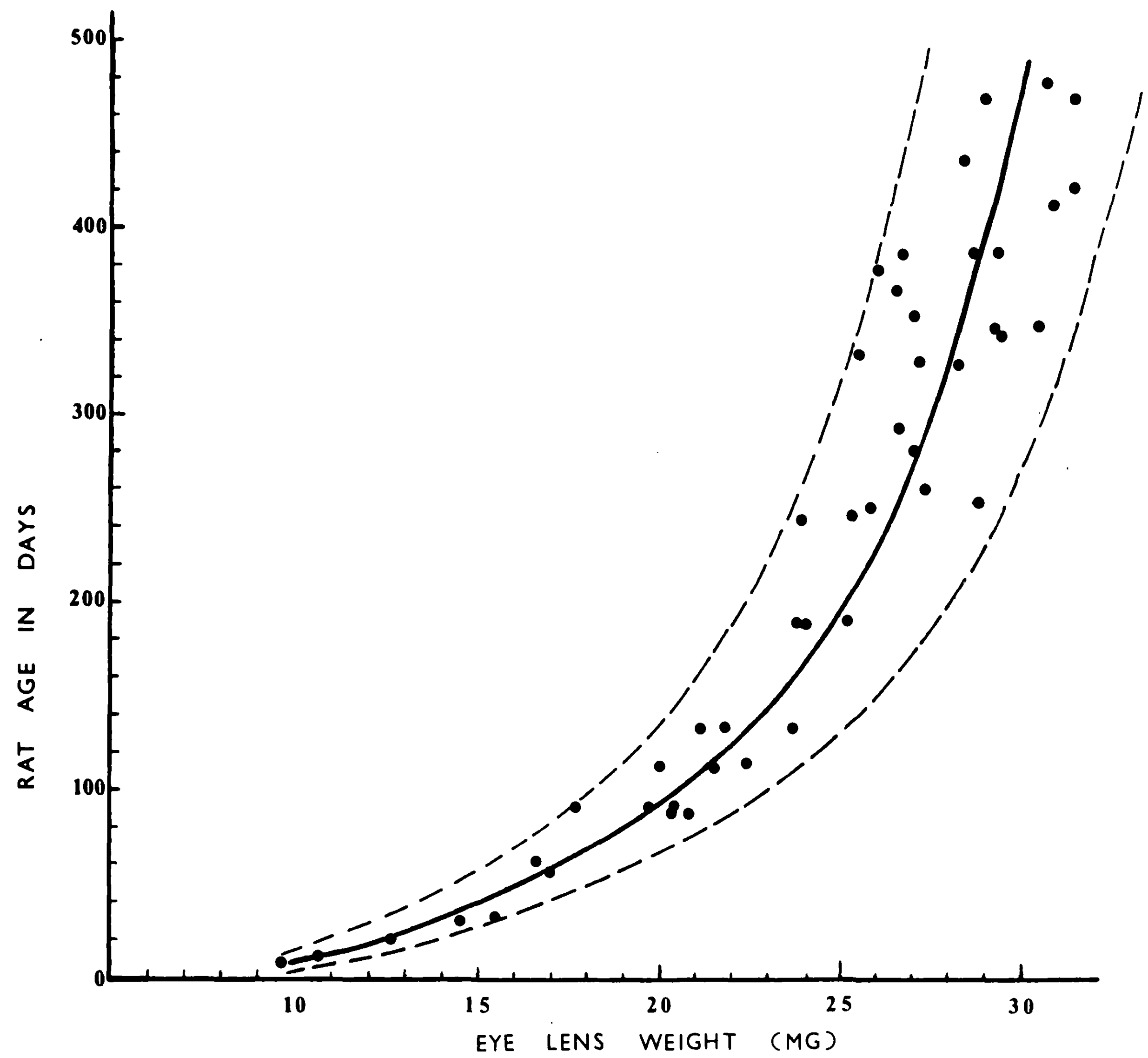

1.7
1.5
1.3
1.1
0.9
0.7
0.5
0.3
0.1
0
1/AGE+59
1.0
1.1
1.2
1.3
1.4
1.5
LOG LENS WEIGHT

FIGURE 2.24

EYE LENS WEIGHT-AGE RELATIONSHIP FOR 46 KNOWN AGE *R. EXULANS*

The regression line and confidence limits are transformed from those shown in Figure 2.23.



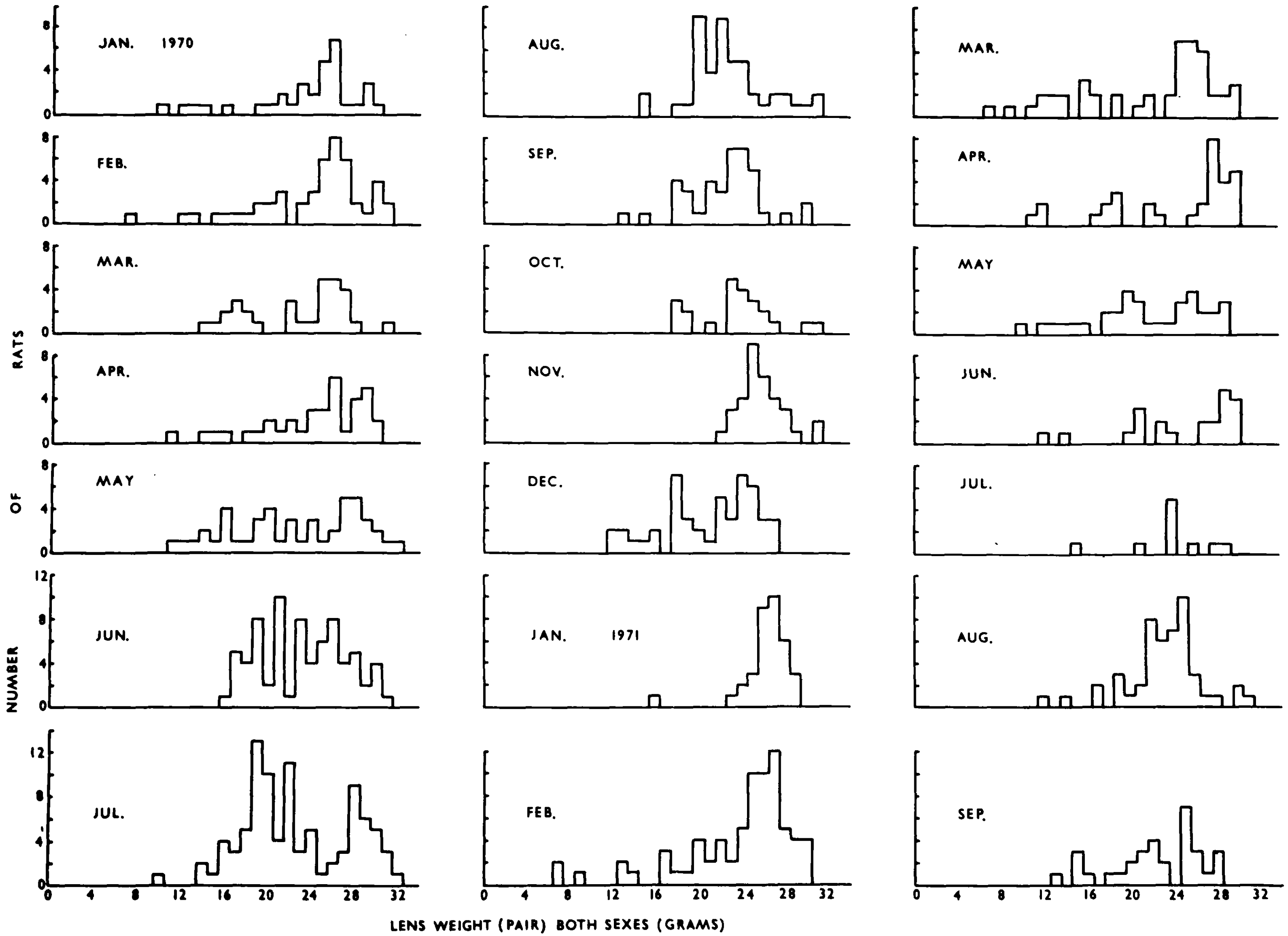
RAT AGE IN DAYS
500
400
300
200
100
0
10
15
20
25
30
EYE LENS WEIGHT (MG)

Because the eye lens technique offered insufficient ageing precision it was not possible to subdivide the Wainigata population sample into enough age classes, on the basis of lens weight, to construct a time-specific life- table. However it was possible to examine the approximate ratios of young and old animals, in the monthly samples, by constructing lens weight frequency histograms (Figure 2.25). These illustrated that the majority of animals in all months had lens weights of 20 mg or greater and therefore were over two months old. Periods of population recruitment became particularly apparent (i.e. July 1970 and March 1971) as did periods of apparent population stability (November 1970 and January 1971). The distribution of eye lens weight also indicates the age at which R. exulans enter the trappable portion of the population. A very small proportion of the total number of animals sampled had a lens weight of less than 15 mg (i.e. the mean age of less than 42 days, Figure 2.25) suggesting that most animals were not trappable until they were at least one month old.

Most investigations of the eye lens as an indicator of age have involved mammals considerably larger than R. exulans which has an average body weight of only 50 g and a combined lens weight of up to only 30 mg. Experimental errors must be proportionally greater when dealing with small lenses, thereby reducing the precision of the technique. Berry and Truslove (1968) found that eye lens was not a useful indicator of age in the house mouse as variablity was extremely high over most of the age range. However, Ostbye and Semb-Johansson (1970) and Martinet (1966) considered that lens weight was a useful

FIGURE 2.25

DISTRIBUTION OF EYE LENS WEIGHTS FOR *R. EXULANS* TRAPPED MONTHLY AT WAINIGATA GRIDS DURING 1970 AND 1971


JAN. 1970
FEB.
MAR.
APR.
MAY
JUN.
JUL.
AUG.
SEP.
OCT.
NOV.
DEC.
JAN. 1971
FEB.
MAR.
APR.
MAY
JUN.
JUL.
AUG.
SEP.
NUMBER OF RATS
LENS WEIGHT (PAIR) BOTH SEXES (GRAMS)

criterion of age for young Lemmus lemmus and Microtus arvalis respectively, despite considerably variability.

While eye lens weight has proved a useful indicator of age for medium sized animals such as rabbits (Lepus californicus, Connolly et al., 1969) and large animals such as seals (Callorhinus ursinus, Bauer et al., 1964), the methods lack of precision when applied to some of the smaller rodents has led to the development of a more sophisticated technique over the last two years (Otero and Dapson, 1972). The technique made use of a biochemical character of the fresh lens, specifically the amount of insoluble protein that was present, and has provided unprecedented accuracy for animals as small as field mice (Peromyscus polionotus) (Dapson and Irland, 1972) Ninety-five percent confidence limits about an average estimation of 100 days were 96-107 days; for 300 days, 293-319 days and for 700 days, 680-751 days. Such accuracy would allow refined demographic studies of wild mammal populations, but it should be noted that the technique requires a considerable amount of sophisticated laboratory equipment which, combined with the need to use fresh lenses, restricts its use.

2.5B REPRODUCTION

As mentioned in Section 2.1 reproduction is a term usually used to cover all processes leading up to the addition of animals to a population. Reproductive success determines, at least in part, the growth of the population, a process that is in turn ultimately affected by the stresses that increased population density induces in many small mammal populations (Christian 1956). Major aspects of reproductive success, ie. breeding seasons, the percentage of the population that breeds and the number of young they produce, were investigated using data gathered during Wainigata grid trapping.

Between September 1969 and December 1971 619 R. exulans females were autopsied as a result of the monthly grid trapping at Wainigata, however only 38 R. rattus females were caught, of which only one was pregnant. Similarly only 3 of the 35 R. rattus females caught during crown trapping in 1972 (Section 2.4C) were pregnant. The lack of pregnant R. rattus in the sample trapped could have been partly due to the decreased trappability that this species exhibits as it approaches parturation (Becker, 1954; Jackson, 1962). R. exulans females do not exhibit such a decrease in trappability during pregnancy (Jackson, 1962). The following discussion of reproduction is therefore confined to R. exulans.

I. Seasonal Distribution of Pregnancy

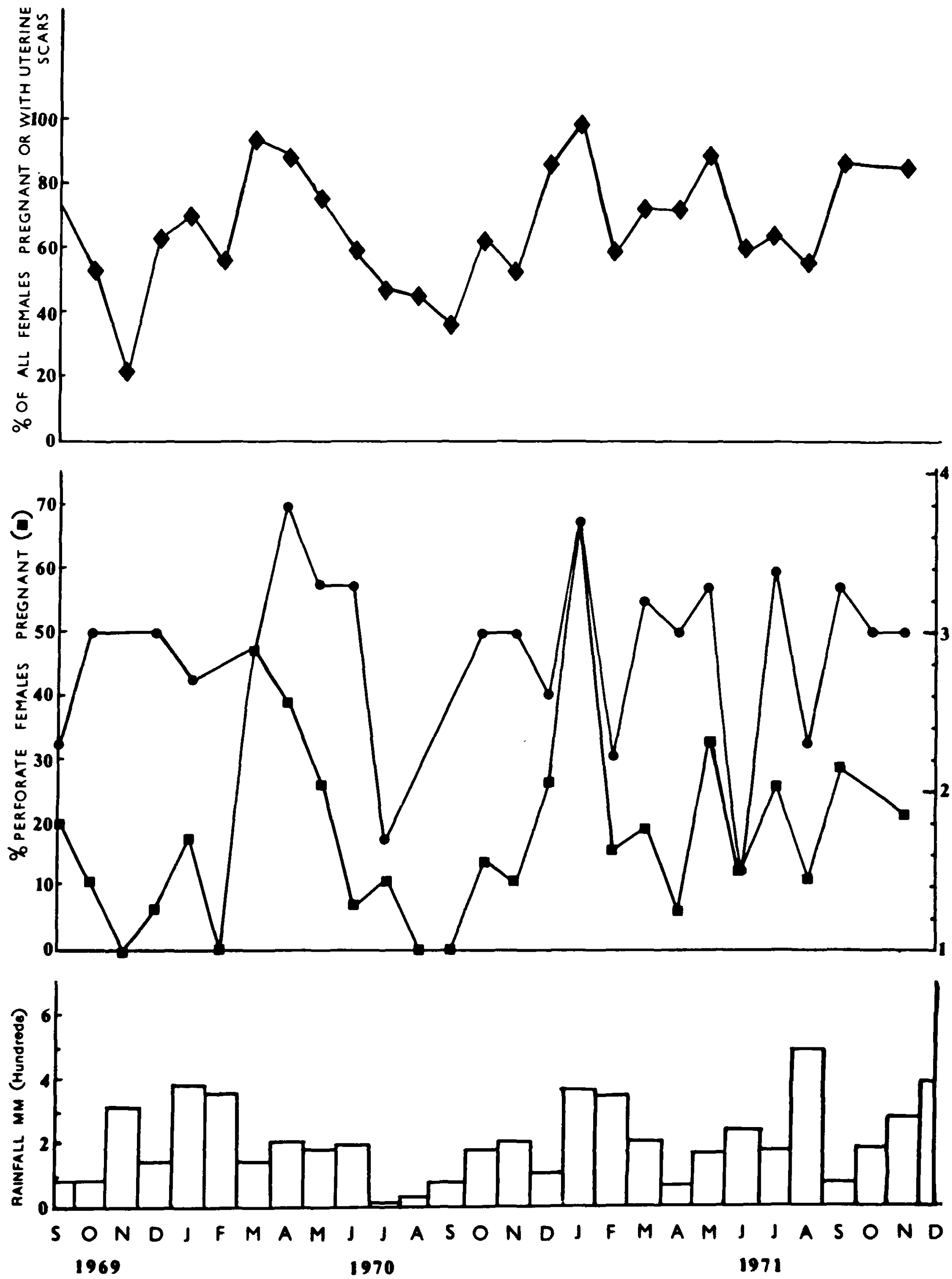
Two pronounced breeding peaks were recorded between September 1969 and December 1971, one in March-April 1969 and the other in January 1971. Between May and December 1971 there were several minor periods of breeding and the prevalence of pregnancy during this period increased above the average value of 18 percent to 21 percent (Figure 2.26). Pregnancy percentages were based on the number of females with perforate vaginas as this character indicated a female was potentially a member of the breeding population.

Rainfall seemed to be the ultimate external factor governing the timing of these breeding peaks and, as discussed in Section 2.5C, this probably operated by regulating available

FIGURE 2.26

FREQUENCY OF R. EXULANS PREGNANCY AND NUMBER OF EMBRYOS PRODUCED PER FEMALE RELATED TO RAINFALL AND THE PERCENTAGE OF FEMALES THAT ARE POTENTIAL BREEDERS

(Top graph)


% OF ALL FEMALES PREGNANT OR WITH UTERINE SCARS
0
20
40
60
80
100
% PERFORATE FEMALES PREGNANT (■)
0
10
20
30
40
50
60
70
EMBRYOS PER PREGNANT FEMALE (●)
1
2
3
4
RAINFALL MM (Hundreds)
0
2
4
6
S O N D J F M A M J J A S O N D J F M A M J J A S O N D
1969
1970
1971

food supplies. The period of generally higher rainfall that followed the mid-year dry season coincided with both the marked breeding peaks, while the above average pregnancy rate between May and December 1971 was associated with a period of consistently higher rainfall. (Figure 2.26).

The breeding peaks appeared to include a second factor, an increase in the number of embryos per pregnant female which combined with the increased pregnancy rate to produce an even larger rise in reproductive output. (Figure 2.26). This increase in the number of embryos, as well as the percentage of perforate females pregnant, applies to only macroscopically visible pregnancies since embryos are normally visible in the uterus for only 18 of the 25 days of pregnancy (Davis, 1953). Nevertheless in the absence of a marked increase in intra-uterine mortality the apparent rise in the numbers of embryos should also add to the overall increase in population. This increase in reproductive output per females also suggested an association with food availability, possibly a particular component of the diet, such as protein.

During the breeding peaks a very high proportion, usually over 90 percent, of the females were sexually mature, as indicated by the fact that they were either pregnant or carrying uterine scars (Figure 2.26). Davis and Emlen (1948) established that this latter feature proved a female R. norvegicus had been pregnant and it was therefore a very satisfactory measure of maturity. The high proportion of mature females in the population during breeding peaks must have also contributed to overall reproductive output.

R. exulans breeding peaks have been recorded at various times of the year in other parts of the species' range (Section 2.1D) but Harrison (1952) found no marked breeding season in Malaya. In most habitats it would appear that marked seasonal changes in precipitation or temperature are the basic factors inducing seasonality in reproduction. Weather based seasonality in breeding was also found to be a characteristic of R. rattus populations at several places in India (Davis, 1953).

The 18 percent pregnant (uncorrected, see below) in Fiji was virtually the same as recorded on Ponape Island in the Marshall Islands, but well below the average of 42 percent in New Zealand (Watson, 1956) and the 27 percent in Malaya (Harrison, 1951).

II. Annual Production

The annual production of a population is basically the sum of the number of young per litter multiplied by the number of litters per year. The first factor, young per litter, is usually based on the number of emryos counted in the reproductive tract of autopsied females. However after becoming visible at the sixth or seventh day of pregnancy 15 to 16 percent of R. exulans embryos are reabsorbed or aborted (Jackson, 1962; Harrison, 1951). Thus if the average number of embryos per female is equated with viable offspring a slight over estimation (approximately 8 percent) of annual production will result. As comparable studies of R. exulans have not applied a correction factor none was used in this study, thus allowing direct comparisons.

The average number of embryos per female at Wainigata was 3.1 which was higher than on Ponape (2.5) (Jackson, 1962) but lower than in Malaya (4.5) (Harrison, 1951) and New Zealand (4.7) (Watson, 1956).

Emlen and Davis (1948) established that the annual incidence of pregnancy, or the number of litters born to a female in a 12 month period could be approximated from estimates of the incidence of pregnancy by applying the equation:

$F = I \times \frac{t}{18}$ where F = Frequency of pregnancy,
I = Incidence of pregnancy (i.e. percentage of rats visibly pregnant)
t = length of time during which specimens were collected (Sept. 1969-Dec. 1970, 850 days at Wainigata).
18 = Number of days in which embryos are normally visible in the uterus.

Davis (1953) proposed that data on which this approximation was based should be standardised to compensate for seasonal differences in the prevalence of pregnancy. Standardisation involved summing the percentage pregnant for all months and then dividing by the number of months. This method essentially assumed that an equal number of rats (100) was caught in each month and was necessary for comparisons of incidences of pregnancy from place to place.

The corrected percentage of perforate females pregnant in Fiji was 19.7 percent which, by applying the equation for determining the annual incidence of pregnancy, $F = 0.197 \times \frac{850}{18} = 9.3$, indicated an annual production of 4.0 litters per year (i.e. 9.3 litters/2.33 years). From this statistic the theoretical number of young produced by each female in a year (the annual production) can be calculated by multiplying the average number of offspring per litter (3.1) by 4.0 litters per year. Thus annual average production for R. exulans at Wainigata was 12.4 which was higher than the 9.8 recorded by Jackson (1962) on Ponape in the Marshall Islands but considerably lower than that recorded by Harrison (1951) in Malaya (25.7) and Watson (1956) in New Zealand (39.5).

III. Summary of Reproduction

The reproductive rates for R. exulans in Fiji were much lower than those reported from Malaya and New Zealand. Both the prevalences of pregnancy and the average litter size were as much as 50 percent less. Nevertheless data from Ponape, a Pacific Island similar to Fiji Islands, was similar suggesting that R. exulans populations on oceanic islands are not under the same pressures as those on large land masses, where predation and competition for resources could be more severe.

The lower level of breeding activity on Pacific Islands suggests that the survival of young and adult R. exulans must be greater than in other populations of this species. Jackson (1962) established that adult mortality on Ponape Island was lower than in Malaya, and this feature probably also applies in Fiji, as survival was also higher (Section 2.5D).

2.5C POPULATION LEVELS

I. Objectives and Methods of Analysis

Estimates of rat numbers were made at three of the survey sites, Salt Lake, Wainigata coconut area and Namara road. At the first and last sites the main objective was to establish whether there was any relationship between the number of rats present and the overall amount of damage inflicted on coconuts and cocoa respectively. At the Salt Lake site an effort was also made to determine if there was any relationship between the availability of other sources of food, as measured by the abundance of seasonal vegetation, and the number of coconuts damaged by rats.

As discussed in Section 2.2B Wainigata grid trapping was primarily established to provide monthly samples for autopsy, but by trapping on a grid layout estimates of population could be derived, thus providing a comparison with Salt Lake estimates.

Population levels at Salt Lake and Namara sites were estimated using the method of Jolly (1965). For comparison purposes (reasons discussed below) population levels were also estimated using the method of Manly and Parr (1968). Early methods of population estimation such as the simple Lincoln Index (Lincoln, 1930) or the methods of Fisher and Ford (1947) and Leslie (1952) were based on deterministic models that assumed that the survival rate of an animal over an interval of time is an exact value. In fact it is more correct to state that an animal in the wild has a probability of surviving over a given interval. This probability is well expressed by the stochastic model, but until Darroch (1958, 1959, cited by Southwood, 1966) showed that the model could yield estimates of population parameters it was thought that the calculations arising from the model would be too complex (Southwood, 1966). Jolly (1965) extended the method to cover populations where there was both loss (death and emigration) and dilution (births and immigration). In addition to providing an estimate of total population Jolly's method also yields estimates of survival rate between sample periods and the number of new animals joining the population between each sample period. Equations for the derivations of standard errors are also provided for these three parameters. All calculations based on Jolly's model were carried out using the computer programme of Davies (1971).

Although Jolly's method is probably the least restrictive of any in use at the present time it assumes that mortality is independent of age. This implies that the probability of an animal surviving through any period of time is not affected by its age at the start of the period, an assumption that is possibly unjustified for rats in a population sampled at monthly intervals. To overcome this deficiency in Jolly's model Manly and Parr (1968) proposed a method of calculating population and survival rate (without standard errors) that does not assume mortality is independent of age. Although Manly and Parr's method does not use data as efficiently as Jolly's it was applied to Salt Lake data to assess whether age dependent mortality had any marked influence on Jolly's population estimates.

Population estimates were also derived from Wainigata grid trapping data (trapping procedures described in Section 2.2) by applying a method described by Zippin (1958). The method is based on removal trapping, the principle being that a known number of animals are removed from the habitat on each trapping occasion thus affecting subsequent catches. The rate at which trap catches fall off is directly related to the size of the total population (unknown) and the number of animals removed (known). A number of conditions must be satisfied before the method can be successfully applied. These have been discussed in detail by Southwood (1966) who considered that the most serious limitation in practice was that the chance of being caught must be equal for all animals. In rat populations very young animals are not caught (Section 2.5A) and there are almost certainly various degrees of 'trap-shyness'. Nevertheless the method does provide a reasonably precise estimate of population, provided a relatively large proportion of the population is caught during the trapping period.

The area to which the derived population estimate related was larger than that actually covered by the grid (i.e. 0.81 ha at Wainigata). During the four or five days trapping animals were removed from the grid area plus a strip around the margin of the grid. Dice (1938) seems to have been the first to demonstrate this feature and since then several workers (Hannson, 1969; Pelikan, 1969) have proposed methods to correct for trap grid edge effects. In general they added a measure, equal to an average home range for the species under investigation, to the edge of the trap grid. Hannson (1969) refined this approach by comparing the population estimate from the central portion of a 5.8 ha grid with that for the grid as a whole.

As the grid used during the present study was much smaller (only 0.81 ha) than Hannson's, population estimation for a central component was not possible. However, to make some allowance for the known edge effect the average distance (Av.D) moved within a trapping period by R. exulans adults (i.e. 11.1 m as calculated from Salt Lake data, Section 2.4B) was added to the edge of the grid, making the effective area trapped 1.26 ha. This measure was also added to the edge of the Salt Lake grid to allow comparisons to be made with Wainigata data. Thus the total area trapped at Salt Lake was 3.15 ha.

II. Results and Discussion

a) Salt Lake

(i) Population levels

The estimates of population, by Jolly's and Manly and Parr's methods, were for all R. exulans and R. rattus captures but because of the marked trap-shyness exhibited by R. rattus (Section 2.4A) the estimates essentially reflect only R. exulans population changes.

The two methods yielded very similar estimates (Figure 2.27) with the only marked differences between them occurring in October 1970 and January 1972. In both these months there was a marked rise or fall in the numbers present, as derived by Jolly's method. This could have been the result of the method requiring the assumption that mortality is independent of age since Manly and Parr's method, which does not make this assumption, shows a much small deviation from the general trend. However as the two methods yielded very similar retuls during periods of gradual population change or relative stability it would appear that age dependent mortality did not have a marked effect on population estimates.

There were two population peaks during the survey period, one in June 1970 and the other January 1972 (Figure 2.27). The June 1970 peak was clearly a major one for it was also recorded at Wainigata during grid trapping (Figure 2.30) In contrast the January 1972 peak was of minor proportions, with the estimate derived by Manly and Parr's method probably being more realistic. Possible reasons for these fluctuations in population numbers are discussed below.

The trappable area of the grid was assessed as being 3.15 ha, that is, the actual area covered by the grid of traps plus the Av.D moved by R. exulans adults within trapping period added to the entire margin. Population estimates thus represented densities of 24 to 58 per hectare, which were higher than most estimates from the Pacific region (Section 2.1E).

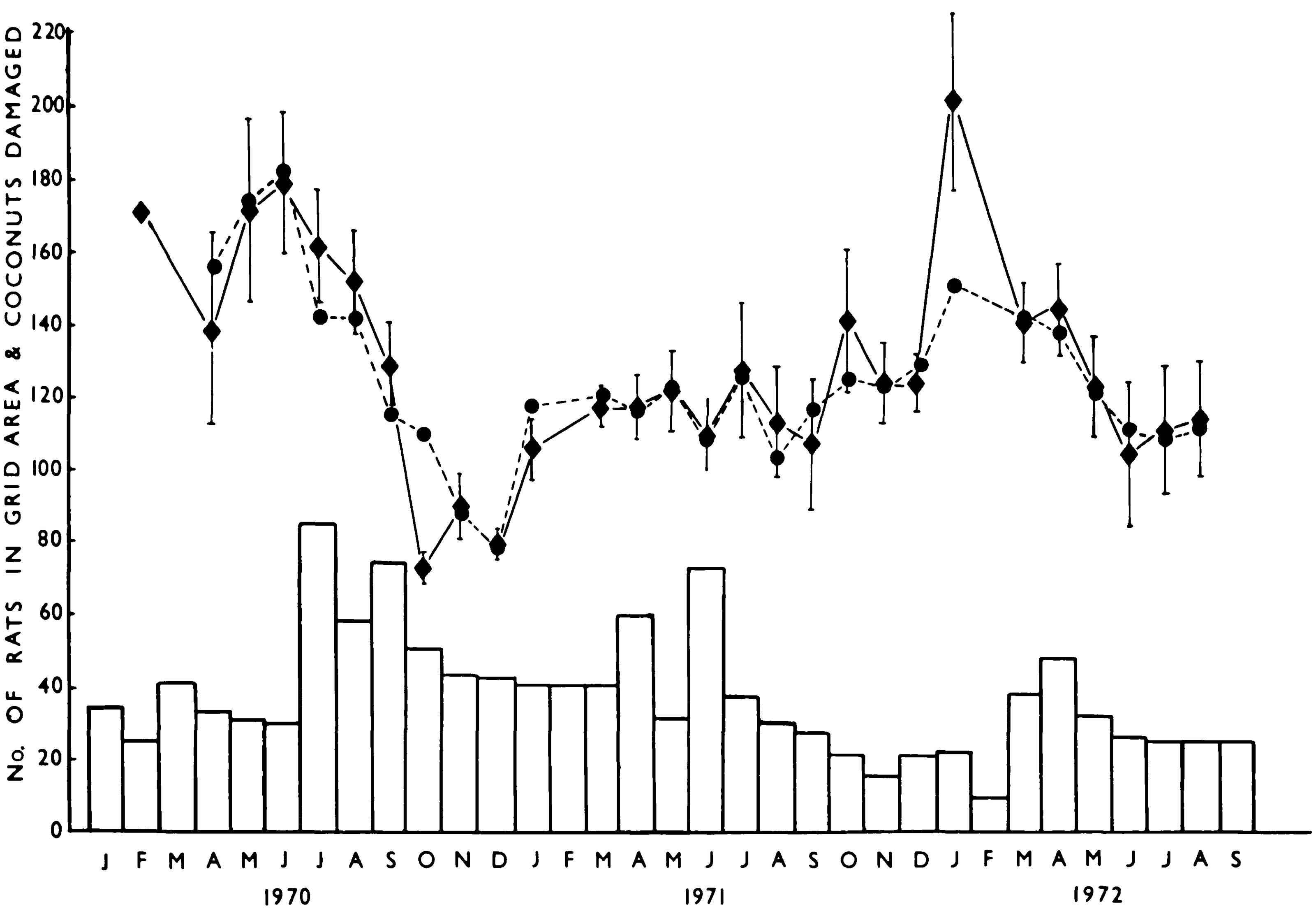
(ii) Levels of rat damage to coconuts

All coconut damage and production from the 60 survey palms within the Salt Lake grid was recorded monthly and classified

FIGURE 2.27

MONTHLY ESTIMATES OF THE NUMBER OF RATS PRESENT (DERIVED BY JOLLY'S METHOD AND MANLY AND PARR'S METHODS) AND THE NUMBER OF COCONUTS DAMAGED AT THE SALT LAKE COCONUT AREA

Solid line = Jolly's method
Broken line = Manly and Parr's method
Histograms = Number of coconuts damaged per 100 palms per month


No. OF RATS IN GRID AREA & COCONUTS DAMAGED
0
20
40
60
80
100
120
140
160
180
200
220
J F M A M J J A S O N D J F M A M J J A S O N D J F M A M J J A S
1970
1971
1972

according to the categories described in Section 3.3B.

There was a general rise in damage following the two population peaks (Figure 2.27) and it was considered that these may reflect increases in the number of older animals in the rat population. An increase that would not necessarily coincide with total population peaks since these would include many young animals that may not have started attacking coconuts. In order to allow for this possible lag in the effect of rat numbers on damage, when testing for correlation between the two factors, all damage survey figures were shifted back two months so as to coincide with population peaks.

There was however, no significant correlation (r = + 0.05, n = 26) between assessed population and the level of damage over the whole survey period. Even for the period April 1970 to January 1971 no significant correlation occurred despite the marked population peak (r = +0.424, n = 11).

The lack of a simple correlation between rat numbers and the level of damage was, at least in retrospect, to be expected as R. rattus' trap-shyness resulted in this species, which caused over 50 percent of the damage (Section 3.2B), being severely underestimated. Other sources of food must also have affected the level of rat damage to coconuts as the numbers damaged by rats at Salt Lake were relatively low (Section 3.3B) and could have provided food for very few animals. The highest level of damage represented a loss of only four nuts per hectare per day during a period when the assessed population was as high as 58 rats per hectare. Clearly few R. exulans or R. rattus were utlising green coconuts as a source of food.

iii) Seasonal changes in vegetation and possible relationship with population levels, the mean weight of adult R. exulans and the number of coconuts damaged

There were marked changes in the height and abundance (as measured by percentage ground cover) of vegetation during the 12 months, April 1971 to April 1972 (Figure 2.28). A full list of significant species usually present within the Salt Lake survey site is tabled in Appendix I. With the onset of drier weather in March and April, dominant herbaceous species such as Kaumoce (Cassia tora) seeded and died back- a process that was reflected in a decrease in the average height of the vegetation as well as a decrease in the percentage of sample sites at which Kaumoce was the predominant species (Figure 2.28). Rain in May and June 1971 started the seasonal cycle again with grasses (nine species) and mile-a-minute (Mikania micranths) spreading out rapidly and causing a steady increase in the percentage of sample sites that were covered by vegetation. With the germination of Kaumoce and the re-emergence of the ginger plant (Amomum cevuga), average plant height increased rapidly during November and December 1971.

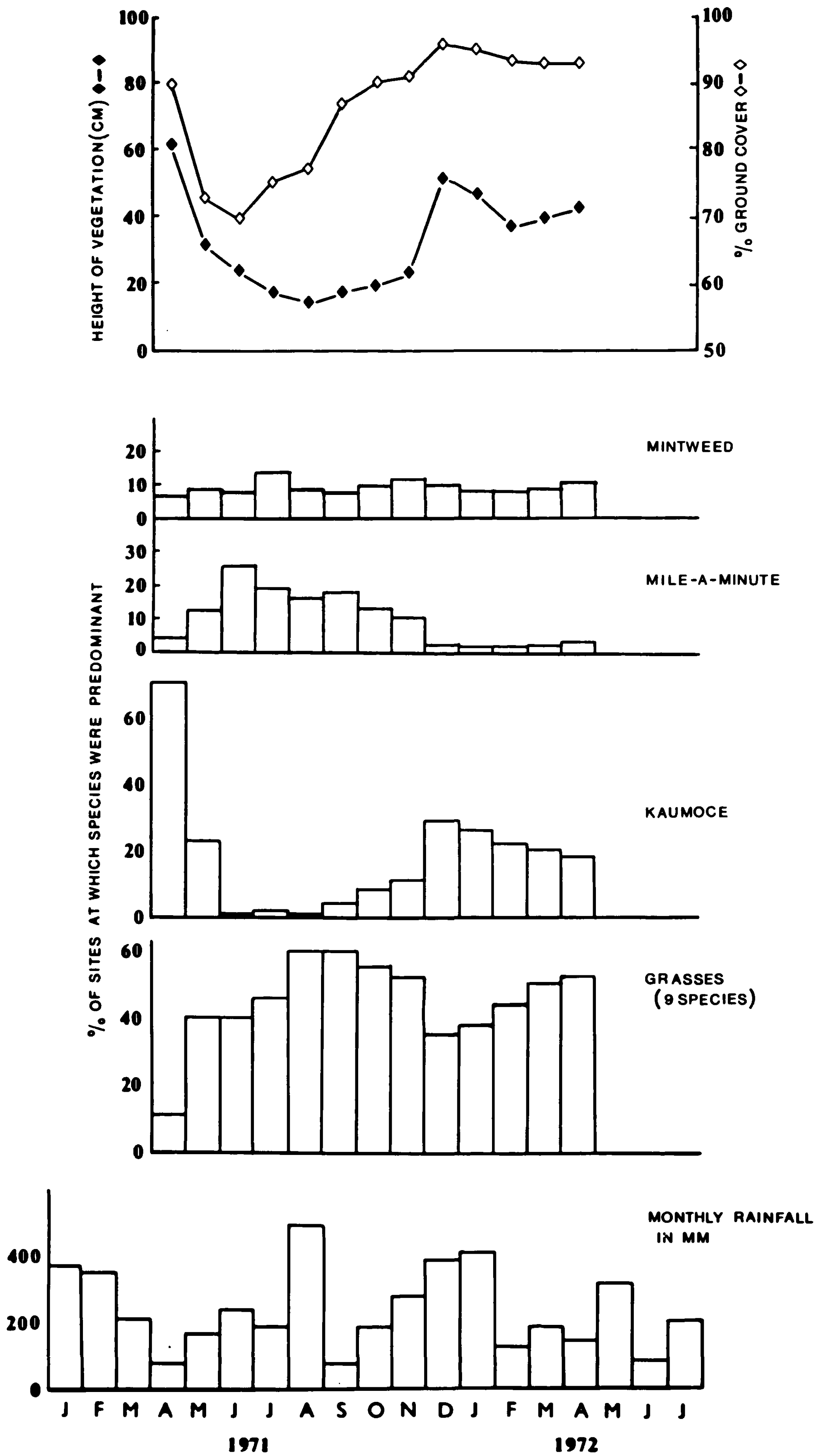
Although this survey of plant growth was carried out for only one 12 month period the pattern of change that emerged was typical of the three years, with actual plant heights and months of maximum growth being dependent primarily on the distribution of rainfall.

As there was no simple correlation between the number of rats present and the level of damage to coconuts it was evident that the availability of other sources of food could be the most important factor influenceing the level of damage. Such food would probably be in the form of plant material,

FIGURE 2.28

THE ANNUAL CYCLE OF ABUNDANCE OF WEEDS AND GRASSES AT THE SALT LAKE COCONUT AREA

Rainfall recorded at Wainigata five Km from Salt Lake



HEIGHT OF VEGETATION (CM)
% GROUND COVER
MINTWEED
MILE-A-MINUTE
KAUMOCE
GRASSES (9 SPECIES)
% OF SITES AT WHICH SPECIES WERE PREDOMINANT
MONTHLY RAINFALL IN MM
J F M A M J J A S O N D J F M A M J J
1971
1972

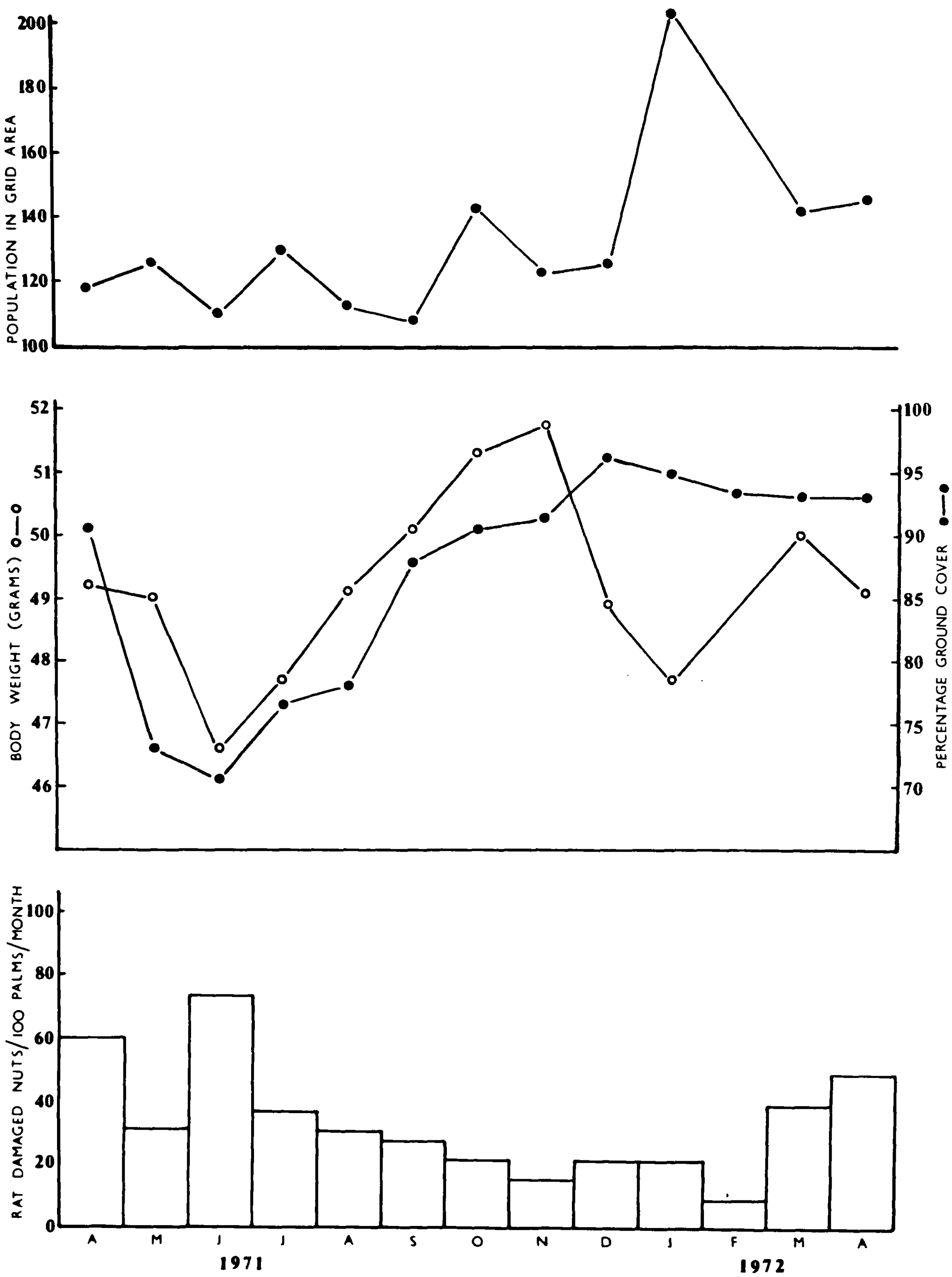
although insects and other invertebrates form a variable proportion of R. exulans diets (Section 2.5E and Fall et al. 1971).

In order to investigate possible relationships, population levels, damage levels, the mean body weight of R. exulans and percentage ground plant cover were compared (Figure 2.29). Mean adult weight was calculated from animals captured on two or more months (thus they were at least two months old) and was derived to provide an index of the "carrying capacity" of the habitat although population density factors, operating through the pituitary-adrenal feedback axis probably also influence body weight during periods of high population density. It was postulated that if the total population remained relatively static (April to December 1971, Figure 2.29) and there was a general rise in the mean weight of the population, more nutritious food must be available. Such a rise in body weight occurred between June and November 1971 (46.6 $\pm$ 1.4 g and 51.7 $\pm$ 1.2 g respectively, Figure 2.29). This steady rise in body weight correlated ($r = +0.81$ $p => 0.01$) with the increase in vegetative growth (as measured by percentage ground cover) that followed the increase in rainfall during May and June (Figure 2.28). The population peak in January caused a decrease in body weight (47.7 $\pm$ 1.5 g) even though most forms of vegetation were at the maximum stage of growth (i.e. height and percentage ground cover, Figure 2.28). This decrease in body weight suggested that the population was exceeding the carrying capacity of the habitat although social factors could have been operating.

The close relationship between the state of the habitat and the weight of R. exulans adults, at least during periods

FIGURE 2.29

THE RELATIONSHIP BETWEEN POPULATION LEVELS AT SALT LAKE, MEAN ADULT *R. EXULANS* BODY WEIGHTS, GROUND COVER AND THE NUMBER OF COCONUTS DAMAGED BY RATS


POPULATION IN GRID AREA
200
180
160
140
120
100
BODY WEIGHT (GRAMS)
52
51
50
49
48
47
46
PERCENTAGE GROUND COVER
100
95
90
85
80
75
70
RAT DAMAGED NUTS/100 PALMS/MONTH
100
80
60
40
20
0
A M J J A S O N D J F M A
1971
1972

of population stability, appeared to have an effect on the level of rat damage to coconuts. Although no statistically significant relationships were established the decrease in the levels of damage from June to November 1971 (Figure 2.29), during a period of population stability and increasing weight, suggested that coconuts may be attacked only when other sources of food are in short supply (June 1971). If a marked rise in population occurred during a period of general food abundance (January 1972) there appeared to be no increase in damage. This interrelationship between the availability of other sources of food, population levels and damage levels could have accounted for the rise in damage at Salt Lake in 1970 (Figure 2.27). This rise coincided with a marked population peak and a notably dry period (Figure 2.30).

Other factors must also affect the relationship between damage levels, population levels etc. In Section 3.3B the relationship between the availability of the size classes of nuts favoured by rats, and the amount of damage is discussed as is the influence of palm height on the species responsible for damage. At the Salt Lake site, where palms were relatively short, R. exulans was responsible for considerably more damage than at other survey sites, where palms were taller. In areas of tall palms R. rattus caused most damage, but owing to the trap-shyness of the species it was not possible to determine either the relationship between absolute numbers and damage (if any) or more complex aspects such as availability of major food items.

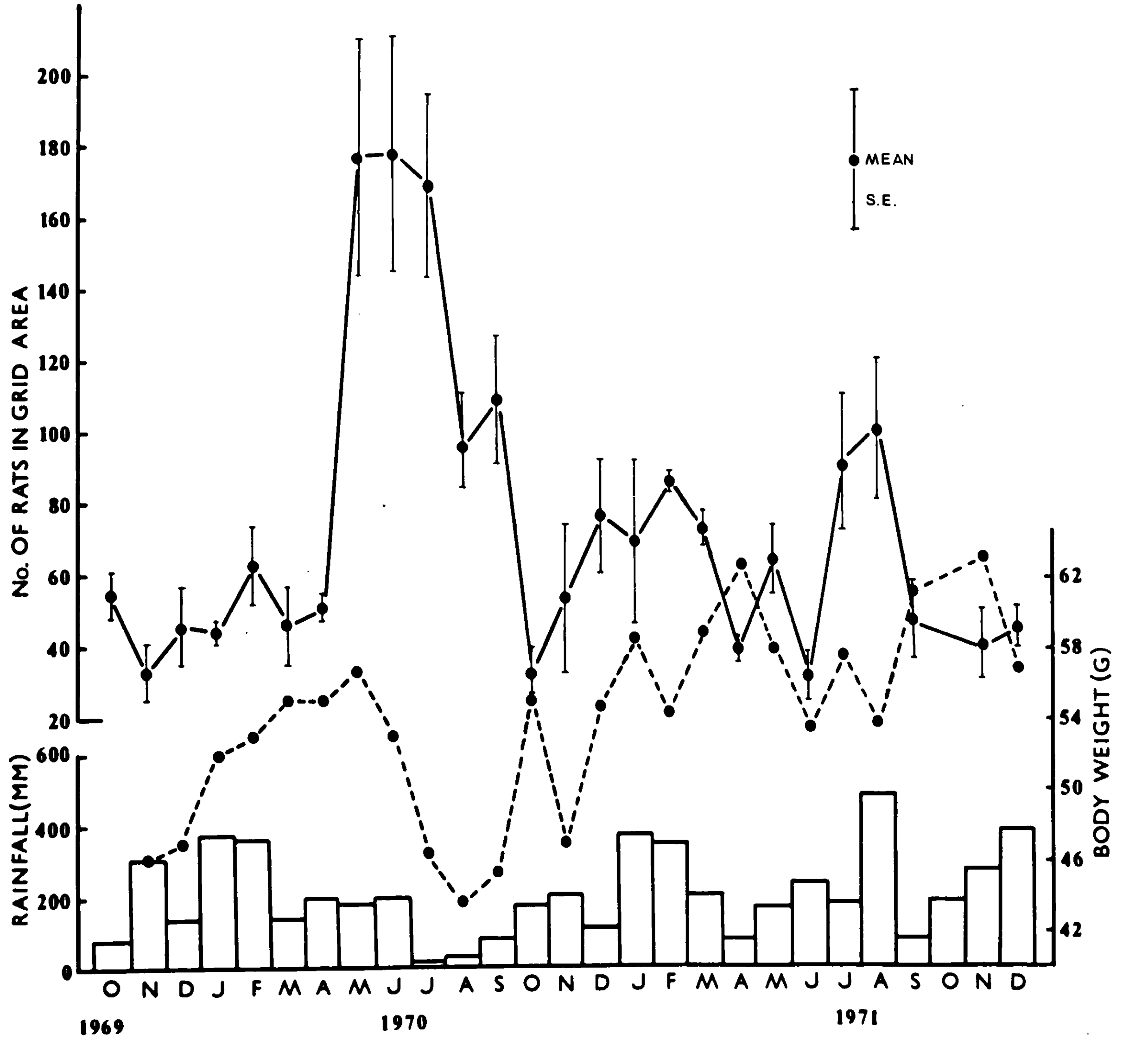
b) Wainigata

Population estimates calculated by Zippin's method were higher during population peaks than those obtained at the Salt Lake site five kilometers away (Figure 2.30).

FIGURE 2.30

MONTHLY ESTIMATES OF THE NUMBER OF RATS PRESENT AND THE MEAN BODY WEIGHTS OF *R. EXULANS* CAPTURED IN WAINIGATA TRAP GRIDS

Solid line = Number of rats
Broken line = Mean body weight
Histogram = Monthly rainfall


No. OF RATS IN GRID AREA
RAINFALL(MM)
BODY WEIGHT (G)
MEAN
S.E.
O N D J F M A M J J A S O N D J F M A M J J A S O N D
1969
1970
1971

Density per hectare ranged from 25 to 137 but the standard errors derived by Zippin's method were considerably higher than those calculated for Salt Lake, using Jolly's method.

There was a marked population peak during June and July 1971, a Rattus population explosion that clearly occurred over a wide area for apart from being recorded at the Salt Lake site farmers reported numerous rats at many sites on the S.E. coast of Vanua Levu and Taveuni.

The mean body weight of adult R. exulans at Wainigata was also calculated in order to establish if there was any relationship with population levels. Rats with a lens weight of 20 mg or greater were defined as adults as these were at least two months old (Section 2.5A). Body weights during July, August and September 1970 were notably lower than earlier in the year (54.8 ± 3.2 g in May; 43.0 ± 1.8 g in August). The very marked drop in body weight coincided with a dry period, and thus a possible shortage of major sources of food, as well as a period of high population density.

c) Namara Road

Population levels at the Namara cocoa site were calculated by Jolly's method for the period June 1971 to September 1972. During this period the number of cocoa pods damaged by rats as well as useable pods (i.e. saleable, see Chapter 5 for cocoa production and damage recording details) produced, were also recorded each week (Figure 2.31).

The area effectively sampled by the grid of tree and ground traps at Namara was calculated on the same basis as Salt Lake and Wainigata. The average adult Av.D. within a trapping period (12.2 m) was added to the margin of the trap grid, making the sampled area 1.7 ha. Calculated population

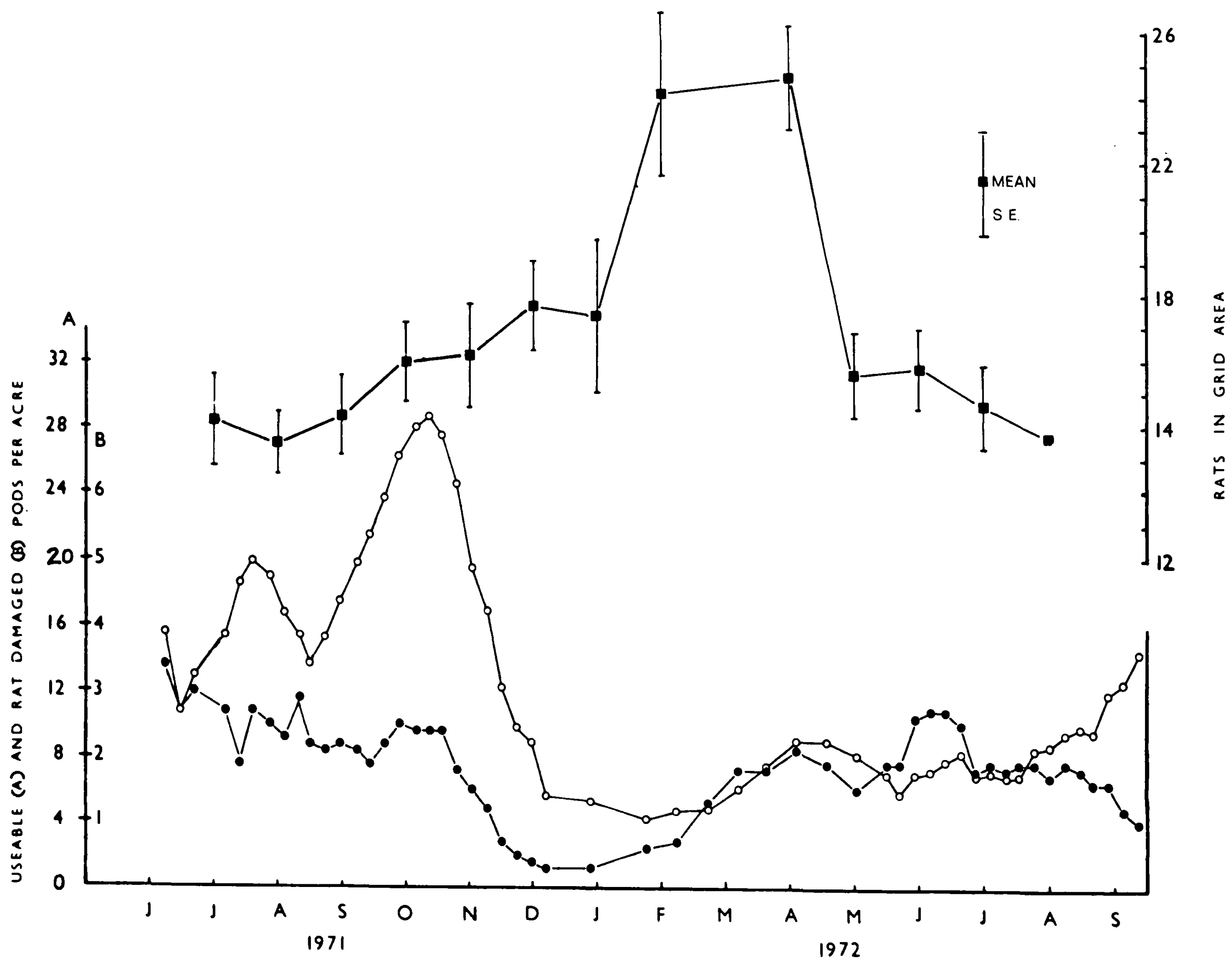
FIGURE 2.31

THE NUMBER OF RATS PRESENT, USEABLE POD PRODUCTION AND PODS RAT DAMAGED

AT THE NAMARA ROAD COCOA PLOT

The plotted lines for useable and rat damaged pods represent a four weekly running mean

Squares = Number of rats in grid area
Open circles = Number of useable pods harvested
Closed circles = Number of rat damaged pods



A
B
USEABLE (A) AND RAT DAMAGED (B) PODS PER ACRE
0
4
8
12
16
20
24
28
32
1
2
3
4
5
6
MEAN
S.E.
RATS IN GRID AREA
12
14
18
22
26
J
J
A
S
O
N
D
J
F
M
A
M
J
J
A
S
1971
1972

(almost exclusively R. exulans) was higher than at Salt Lake, ranging from 80 to 145 per hectare. One marked population peak occurred between January and May 1972 (Figure 2.31), a period when a similar peak was recorded at Salt Lake.

There was clearly no relationship between R. exulans population levels and the number of pods damaged by rats. Possible dietary based reasons for this lack of relationship have been discussed above. However little correlation between population numbers and damage could be expected when the species responsible for most of the damage to cocoa (R. rattus, Section 5.3A) was not adequately represented in the population estimate. In addition the period of maximum rat numbers coincided with a very low level of production, so there were few pods to be attacked. Seasonal characteristics of rat attack of cocoa are discussed in detail in Section 5.3C.

2.5D RATTUS EXULANS SURVIVAL

Jolly's method of calculating population from capture-recapture samples also provides an equation for the estimation of survival from one sample period to the next. As samples, i.e. trapping periods at Salt Lake and Namara Road, were primarily at monthly intervals the calculated survival rate was therefore a monthly survival rate. The probability of survival between all trapping periods was calculated using Davies' (1971) computer programme for Jolly's method of population analysis. A complete list of results are tabulated in Appendix II (Salt Lake) and Appendix III (Namara Road).

Monthly survival rates at Salt Lake did not vary greatly from month to month although the lowest probability of survival was recorded during a month of highest population density (January 1972, 0.57. Appendix II). A similar surival pattern emerged at Namara Road.

From all the monthly estimates of survival a mean monthly survival rate was derived. This was 0.78 and 0.76 respectively for Salt Lake and Namara Road R. exulans populations. By raising these monthly survival rates to the twelfth power an annual survival rate can be approximated (Jackson and Barbehenn, 1962). For Salt Lake and Namara Road these were 0.055 and 0.037 respectively, which was higher than that calculated for R. exulans in Malaya (0.023; Harrison, 1956).

Harrison's estimate of survival was also based on the disappearance of marked rats so the estimates from Fiji and Malaya are comparable and seem to accurately reflect population characteristics because reproductive rates were lower in Fiji (12.4/year) than Malaya (25.7/year)(Section 2.5B). The survival rate of a naturally regulated population governs the population's rate of reproduction. If calculated survival in one area is higher than in another (i.e. Fiji versus Malaya) it follows that the area of higher survival (Fiji) should have a lower rate of annual reproduction.

If the survival rate between sampling periods was not markedly influenced by age, and the differences between population estimates derived by Jolly's and Manly and Parr's methods suggest that it was not (Section 5.4C), then the mean length of life could be derived from the equation 1/log s, where s = constant survival rate per month (Harrison, 1956). Mean length of life for R. exulans populations at Salt Lake and Namara Road was therefore 4.0 months (1/log of 0.78) and 3.6 months (1/log of 0.76) respectively.

It was of note that the monthly survival rate, and therefore mean length of life, was higher at Salt Lake than Namara Road. Several factors could account for this difference. Population densities at Namara Road were consistently higher than at Salt Lake (Section 2.5C) which would probably cause, via density dependent factors, higher mortality. In addition the mongoose population was considerably greater at Namara Road and almost certainly produced a higher level of predation on the Rattus population.

Survival can also be investigated by following the fate of animals marked at a known age. Using Salt Lake data R. exulans weighing 30 g or less were designated as juveniles (Section 2.3B). Most of these animals were probably one month old; an acceptable starting point for an investigation of survival since most earlier mortality could be considered to have taken place prior to weaning.

Table 2.11 THE SURVIVAL OF MARKED R. EXULANS CAUGHT AS JUVENILES AT SALT LAKE DURING TRAPPING PERIODS 1-23

Age (months)	Number caught in each age category		Percentage of animals captured in month 1 caught in subsequent months.	
	male	female	male	female
1	86	88	100.0	100.0
2	54	57	62.8	64.8
3	46	49	53.5	55.7
4	40	40	46.5	48.5
5	31	33	36.0	37.5
6	26	29	30.2	33.0
7	20	26	23.2	29.6
8	17	19	19.8	21.6
10	11	18	12.8	20.5
11	4	7	8.1	15.9
12	3	3	3.5	4.6
13	2	3	2.3	3.4
14	2	3	2.3	3.4
15	1	3	1.1	3.4
16		3		3.4
17		2		2.3
18	2	2	2.3	2.3
19		2		2.3
20		1		1.1

The fate of animals marked as juveniles between trapping periods 1 and 23, January 1970 to January 1972, were tabulated according to the number of months survived. As trapping was continued until October 1972 there was little truncation of estimated survival by using the first 23 of the 31 trapping periods. Females appeared to have a higher rate of survival than males with 4.6 percent living for 12 months, while 3.5 percent of males survived the same period. It is also of note that one female survived 20 months, 5 months longer than any marked male -(Table 2.11). Jackson and Barbehenn (1962) found a similar difference between the survival of male and female R. exulans on Ponape Island and postulated that wider ranging males (see Section 2.4B, Movement) were exposed to more environmental hazards, such as predators, and thus sustained higher mortality.

While the investigation of the survival characteristics of R. exulans in Fiji was of very limited extent, it indicated that the survival of Fiji populations was similar to that recorded for Rattus species in other tropical habitats. Harrison (1956) derived a mean monthly survival rate for 11 Rattus species in Malaya. Monthly survival ranged from 0.72 to 0.90 (0.73 for R. exulans). Mean life span ranged from 3.2 months (R. exulans) to 9.0 months for a Rattus rattus subspecies (jarak).

2.5E FOODS OF R. EXULANS AND R. RATTUS

Although there was only a limited amount of quantitative data on the food habits of R. exulans and R. rattus available when the project was established, a very detailed investigation of Rattus diets, using microtechniques, was considered beyond the major aims of the study. In retrospect a detailed study of diet should have been given higher priority for it may have revealed reasons for the marked variation in damage to coconuts at different sites.

Rudge (1968) , working with the common shrew (Sorex araneus) found that fragmentation of insect prey, unequal digestion time, and rapidity of passage through the gut made quantitative analysis of stomach contents very difficult. Such problems apply, though to a lesser extent, to the analysis of rat stomach contents. Thus a listing of the presence or absence of food items is probably the most meaningful method of expressing stomach analysis results.

At the conclusion of live trapping at Salt Lake in Ocrober 1972 the whole area was intensively trapped with break-back traps, placed at the gound sites as well as in the crowns of 60 palms. Stomachs from these animals were collected and preserved in 70 percent alcohol.

Thirty stomachs from R. exulans trapped on the ground and 15 from R. rattus trapped in palm crowns were examined by washing the stomach contents into a petri dish, draining off the excess fluid and viewing under a binolcular microscope. As fresh coconut kernel was used as bait this tended to dominate most stomach contents. It was evident that the break-back traps were not releasing as soon as a rat touched the bait.

By sorting the stomach material and examining different food items on a microscope slide it was possible to define six major food categories (Table 2.12). Plant foods predominated in the diets of both species but there was also a high incidence of insect, pupae and animal flesh. Lizard or gecko remains occurred in the stomachs of both species, suggesting they provide a significant source of animal protein. R. rattus stomachs had a higher incidence of all animal remains suggesting this species favoured or has a greater dependence on such foods

Table 2.12 FREQUENCY OF OCCURRENCE OF MAJOR FOOD ITEMS IN THE STOMACHS OF 30 R. EXULANS TRAPPED ON THE GROUND, AND 15 R. RATTUS TRAPPED IN PALM CROWNS, AT SALT LAKE

Food Item	R. exulans		R. rattus	
	No.	Percentage	No.	Percentage
Grass or weed seeds	8	27	3	20
Grass stalk material	10	33	2	13
Other vegetation	27	90	12	80
Insect exoskeleton	20	67	13	87
Pupae and Larvae	1	3	2	13
Animal felsh, including Lizard and Gecko remains	9	30	5	33
Nematodes	5	17	9	60

than R. exulans. Stomach nematodes (not identified) were present in three times as many R. rattus stomachs as R. exulans and may reflect the difference in food preference.

The incidence of vegetation and animal matter in the stomachs of the two species at Salt Lake were similar to those that have been recorded in other Pacific habitats (Sction 2.1G). Most studies have found R. exulans to have a higher proportion of vegetation in the diet than R. rattus and Williams (1971) postulated that R. exulans has lower protein requirements. It is unlikely that the palm crowns at Salt Lake, where all R. rattus were trapped, had a higher insect population than the ground sector of the nabitat from which R. exulans were collected.. Thus the opportunity to eat insects and other small animals should have been approximately the same. Fall et al. (1971) found a similar situation to exist between R. rattus and R. exulans on Eniwetok atoll. Animal remains (insect parts etc.) occurred in 45 percent of the R. rattus stomachs but less than 10 percent of R. exulans, despite the fact that the habitats occupied by the two species appeared to contain similar insect populations.

The importance of animal protein in the diet of rats cannot be determined without greater knowledge of the protein content of vegetation used as food; however the apparent difference in the animal protein content of the two species investigated could have a bearing on the amount of damage done to developing coconuts. R. rattus made much more use of the vertical component of the habitat (Section 2.4) and as a result was responsible for a high proportion of the damage to coconuts in Fiji (Section 3.2B). Although the species exhibited considerable trap-shyness (Section 2.4A), resulting in an underestimation of numbers based on live-trapping, crown trapping with break-back traps provided an estimate of relative numbers and indicated that the nuts on many palms visited were not attacked(Section 3.2C). It appeared that population levels and movements had little relationship to the level of damage. The continual contact between the pest species and the target crop, but frequent absence of damage, suggested the crop may not have been a favoured food, and in the case of R. rattus this could possibly stem from the apparently high protein requirements of the species. Although R. exulans appears to prefer a diet composed mostly of vegetation, and could be expected to attack coconuts, it does not climb as readily as R. rattus and therefore does not encounter green coconuts as frequently

RAT DAMAGE TO COCONUTS

Chapter 3

3.1 REVIEW

Rat damage to coconuts has been reported in most Pacific territories, Jamaica and the Laccadive Islands of the Indian Ocean. Lassalle-Sere (1955) reported that 28.0 percent (9.6 nuts/palm/year) of the nuts produced were damaged by rats in Tahiti and Dumbleton (1955) estimated losses for French Oceania to be 50.0 percent of the crop. In Jamaica a survey over several years recorded damage ranging from 5.0 to 71.0 percent (1.8-30.6 nuts/palm/year) (Smith, 1967), while a survey in the Gilbert and Ellice Islands (Smith, 1969) indicated that rat damage ranged from 10.0-77.0 percent (2.8-23.2 nuts/palm/year). Two recent estimates of damage in Tonga reported losses of 5.0 percent (2 nuts/palm/year) on Tongatapu (Pierce, 1971) and 13.0 percent (6.6 nuts/palm/year) on Vavau (Whelan, 1971). Menon and Pandanlan (1957) noted that rat damage on the Laccadive Islands was reported to reach 50.0 percent of production.

Rats have been considered an agricultural problem in Fiji for many years, particularly in relation to coconuts. However, as early as 1883 they were regarded as a pest of sugar cane and in that year the mongoose, Herpestes auropuntatus, was introduced in a control attempt.

After discussions with planters, Turbet (1925) estimated that 10.0 percent of the coconut crop was being lost to rats. Taylor (1930) made the earliest detailed assessment of rat damage to coconuts and calculated losses as 6.8 percent (3.6 nuts/palm/year) of the total crop, a figure based on the number of nuts on the fourth bunch and the mature bunches. He considered that premature nutfall from causes other than rat attack occurred before the bunch was four months old and that most subsequent losses prior to harvest, were due to rats. Paine (1934), dissatisfied with Taylor's estimate, undertook a further study. Regular counts of damaged nuts on the ground at one site (Ura, Taveuni), were supported by a widespread survey similar to that carried out by Taylor (1930). Overall loss was estimated at 28.0 percent (about 23 nuts/palm/year) of the total crop.

From 1934 until the start of the present study no detailed estimates of rat damage to ooconuts were carried out, although a few spot checks of damage were made (Yelf, 1964; Marshall, 1965). Despite the apparent lack of information on rat damage levels, or the species responsible for damage, an attempt was made to get farmers to use trunk bands of aluminium to reduce damage (Yelf, 1966). However, it appears that the initial cost of bands, combined with a paucity of economic data to support their use, resulted in few farmers adopting this method for reducing rat damage.

3.2 FEATURES OF RAT ATTACK ON COCONUTS

3.2A CHARACTERISTICS OF DAMAGE

Typical rat damage to coconuts consisted of a single hole of approximately 65 mm found on the side of the coconut on or near the point of attachment (Figure 3.1). As rats were apparently unable to gnaw into the kernel of mature or nearly mature coconuts, despite intensive attempts (Figure 3.2), immature coconuts were attacked in the palm crown (Figure 3.3). The normal time lapse from rat attack in the palm crown, to

FIGURE 3.1

TYPICAL RAT DAMAGED COCONUT SHOWING EXTERIOR AND INTERIOR

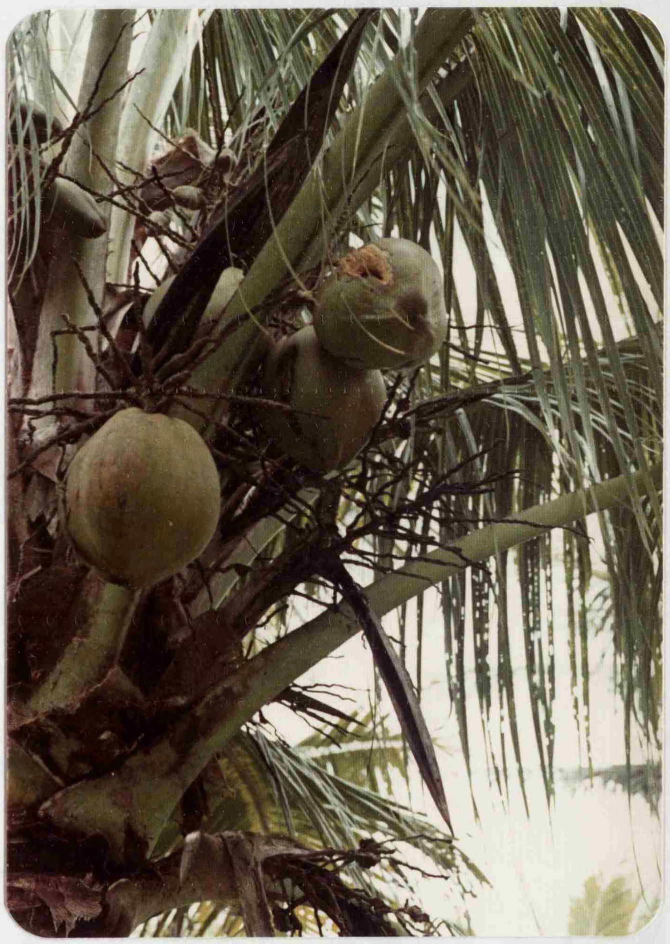
Notes the virtual absence of coconut kernel.

FIGURE 3.2

MATURE COCONUT THAT HAS BEEN ATTACKED BY A RAT BUT NOT PENETRATED

FIGURE 3.3

FRESH RAT DAMAGED COCONUT, AGED APPROXIMATELY SIX MONTHS



detachment of the holed or partially holed coconut from the inflorescence, was three to five days (Section 3.2B).

Damage was concentrated on coconuts between 10 and 20 cm in length, length being the longitudinal axis of the coconut (Table 3.1).

Table 3.1 SIZE CLASS DISTRIBUTION OF DAMAGED COCONUTS

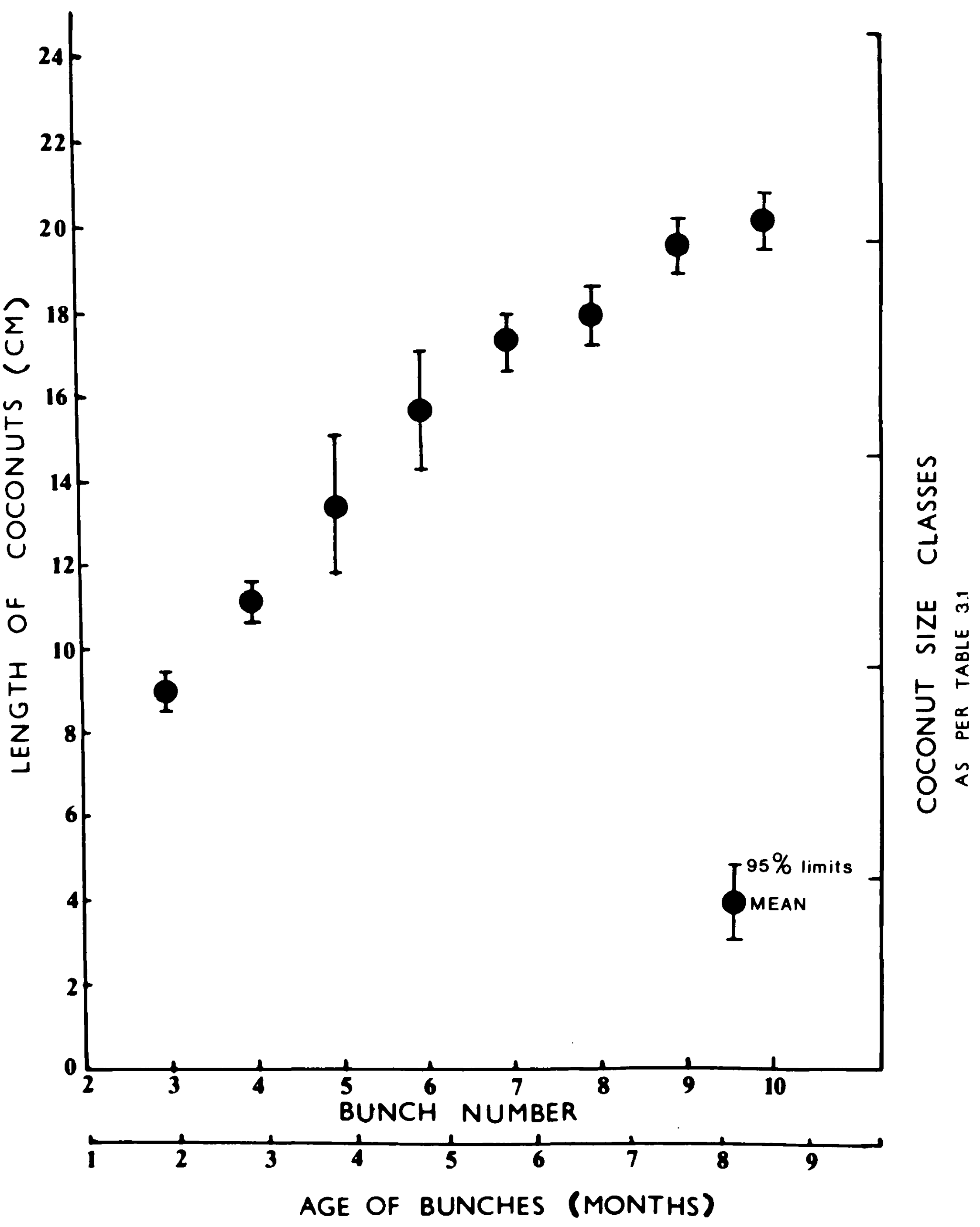
	Size classes (cm)				
	0-4.5	5-9.5	10-14.5	15-19.5	20-24.5
Percentage damaged (n = 1292)	0	2	30	61	7

To determine the relationship between the length of damaged nuts, the age, and the bunch on which they were borne, coconuts on bunches of known age were measured (Figure 3.4). It was evident that coconuts on bunches four to eight (three to seven months old) were favoured.

Endosperm is not present until the sixth month and even by the eighth month it forms only a 6-8 mm thick gelatinous layer (Figure 3.5). Since over 90.0 percent of the damage occurred before the eighth month (i.e. the coconuts are less than 20 cm long), rats gained access to very little endosperm. They may lick the sweet husk sap and drink the coconut water but the amount of debris around a freshly damaged coconut suggested they consumed little of the small section of husk removed. Little damage took place before the developing nuts were three months old, despite claims by earlier authors that damage to very young (less than two months old) or button nuts was important (Marshall, 1965; Yelf, 1966).

FIGURE 3.4

THE RELATIONSHIP BETWEEN NUT LENGTH, BUNCH NUMBER AND THE AGE OF DEVELOPING COCONUTS

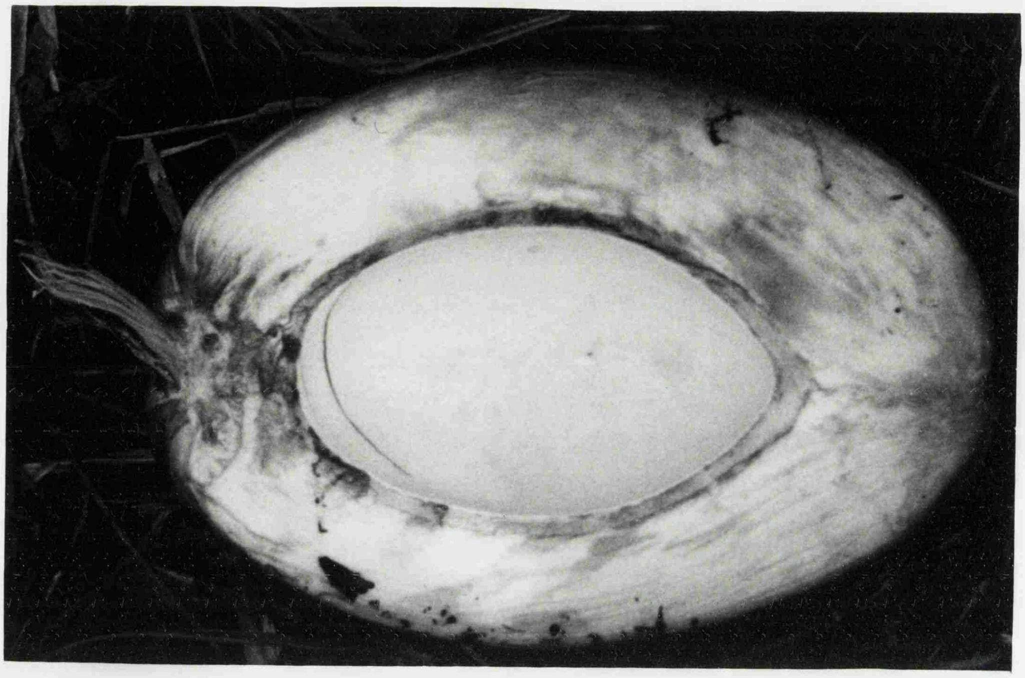


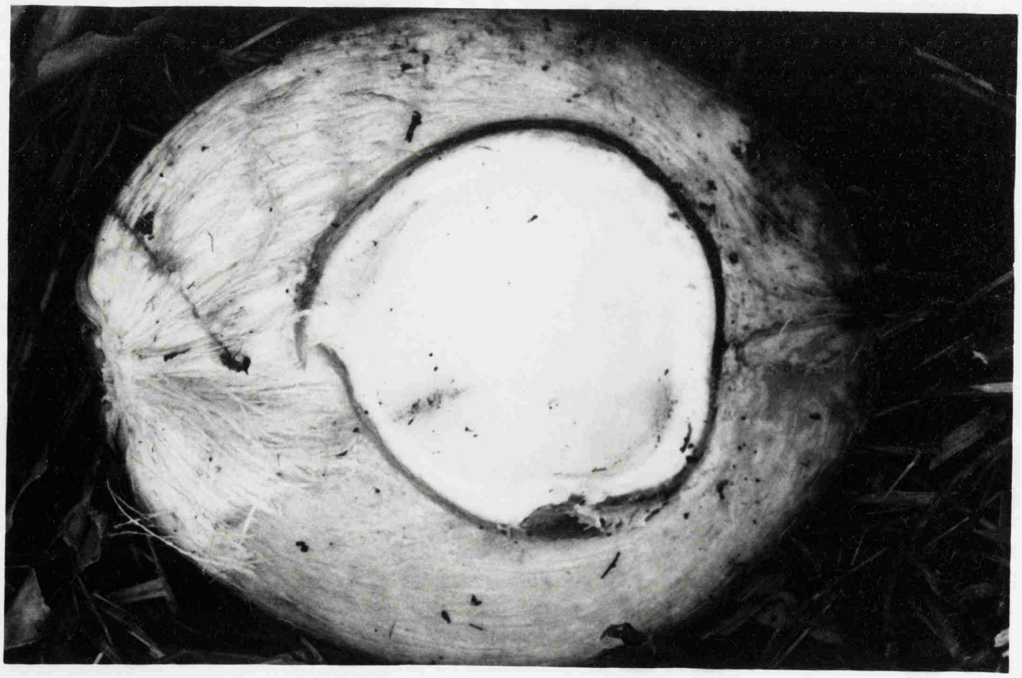
LENGTH OF COCONUTS (CM)
24
22
20
18
16
14
12
10
8
6
4
2
0
2
3
4
5
6
7
8
9
10
BUNCH NUMBER
1
2
3
4
5
6
7
8
9
AGE OF BUNCHES (MONTHS)
COCONUT SIZE CLASSES
AS PER TABLE 3.1
95% limits
MEAN

FIGURE 3.5

DEVELOPING COCONUTS TO SHOW THE GROWTH OF KERNEL

Top = Five month old coconut
Bottom = Eight month old coconut





Yelf (1966) suggested that the feeding activity of rats on male coconut flowers "probably damaged female flowers as well, causing the small immature coconuts to fall". He inferred that female flowers were damaged by rats walking over them, however extensive inspections of inflorescences during the present survey revealed virtually no damage to the lower spathe or female flowers. Minor damage to the male flowers was observed, but as there was a considerable excess of pollen this was unlikely to have an effect on production. Marshall (1965)observed rats chewing male flowers but also concluded it would not affect coconut production.

3.2B SPECIES RESPONSIBLE FOR DAMAGE

Direct observation of R. rattus attacking green coconuts (Marshall,1965) and the presence of damaged nuts on an island inhabited by only R. exulans (Wodzicki, 1969) have established that both species will damage the crop. However as R. rattus foraged arboreally far more extensively (Section 2.4C) at greater heights than R. exulans it could reasonably be expected that they would cause more damage in Fiji's predominantly mature plantations where the majority of palms exceed 8.0 m in height.

To assess the amount of damage done by the two species, teeth marks on damaged nuts were investigated. It was established, by measuring the incisor marks (under a microscope) made in a developing coconut with a cleaned skull, that adult R. rattus incisors made cuts of 2.5-2.8 mm in width while R. exulans made cuts 1.3-1.6 mm wide. This technique was then used to identify the species responsible for damaging coconuts in different plantations but could only be applied to freshly damaged green coconuts, as any shrinkage of the husk with drying out altered the cut dimensions. Juvenile R. rattus made narrower cuts than adults but the percentage of damage inflicted by juveniles was considered to be low because the number of such animals in the Fiji Rattus population was usually less than 25 percent of the total (Section 2.5A).

A survey of damaged nuts at the Salt Lake site, an area containing short palms, revealed that both species were responsible for damage; of the 46 fresh nuts examined over a period of one year 21 had been attacked by R. exulans, 25 by R. rattus. At other survey sites on the Vanua Levu coast, where the majority of palms were over 10 m tall, inspection of 75 freshly damaged nuts revealed that 72 could be attributed to R. rattus, the remainder being the result of R. exulans attack. These results showed that R. rattus was responsible for most of the damage in Fiji and reflected the vertical distribution of the species (Section 2.4C).

3.2C FACTORS GOVERNING RAT ATTACK OF COCONUTS

Crown trapping of palms, varying in height from 8 to 14 m, showed that an average of 48 percent of the palms were visited by at least one species over a period of three nights (Table 2.7). This suggested that most palms in a plantation would be visited over a period of two weeks. However continuous monitoring of rat damage on individual palms revealed that only a small percentage of palms incurred damage in the fortnightly intervals between recordings. On three long term survey plots (Section 3.2B) in the same area as the crown trapped sites (Table 2.7) only 11.6 percent of the palms sustained rat damage over an average two weekly period (mean of all collections during 1971 and 1972). Crown trapping and damage surveys at Salt Lake revealed a similar pattern of activity. Over a six month period in 1972 rats were caught in 17 of the 60 palms under damage survey but 12 of these had lost less than four coconuts during the previous year while the remaining five had been consistently attacked during the previous three years (Section 3.3B).

It was apparent that the presence of rats in palm crowns could not be due simply to the presence of food in the form of green coconuts, for the nuts on some palms were seldom attacked even though the palm was visited by rats. An attempt was therefore made to determine what factors induced rats to consistently attack coconuts on some palms and not others.

Various plantation owners claimed that rats favoured softer, sweeter coconuts borne by some Fiji Tall palms. As rats were known to be attracted by foods sweetened with sugar or saccharin (Barnett and Spencer, 1953; Burright and Kappauf, 1963) an attempt was made to compare sugar levels in the husk of developing nuts from palms favoured by rats, with those from palms seldom attacked. The nuts selected for analysis of sugar were of the age most frequently attacked on any palm (Figure 3.4 and Table 3.1) and the sub-samples were taken from the same site on each nut. Samples from 35 high and low damage palms were analysed, by the Chemistry Section of the Department of Agriculture, for the presence of reducing sugars (fructose and glucose) since Nathanel (1952) had shown that these sugars reached a peak concentration, about five percent, when the developing nuts were five to six months old, the age favoured by rats. The results of this very limited assessment of sugar levels indicated there was little difference between sugar concentrations in nuts from high and low damage palms (4.5 ± 0.19 and 4.9 ± 0.27 percent respectively). However extraction of fluid from the husk proved to be difficult and as there was considerable variation in the assessed sugar levels for nuts from the same palms, these results could not be considered definitive. In effect they only confirmed Nathanel's (1952) findings. This conclusion does not exclude sugar as a possible attractant but certainly does not establish it as a basis for the marked concentration of damage on some palms.

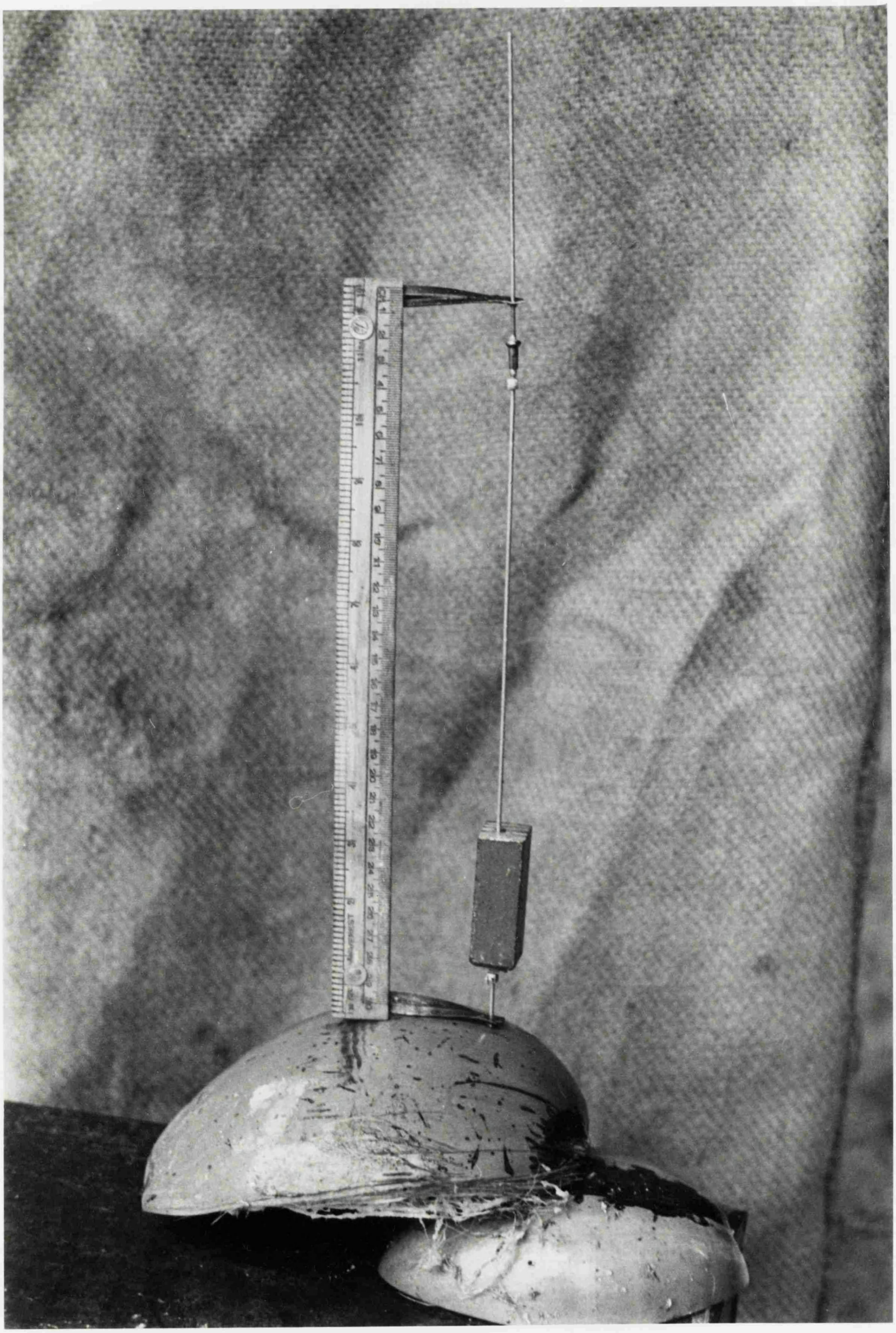
Husk hardness was also investigated using an instrument specifically designed to measure this parameter (Figure 3.6). It consisted of a flat ended steel rod 2 mm in diameter, onto which was threaded a metal weight, the whole being supported by two brackets attached to a 30 cm wooden ruler. When the instrument was in place on a coconut the weight could be raised a known distance (the same distance was used in all tests), dropped onto a fixed step on the steel rod which then penetrated the coconut a measurable distance (7-28 mm). In reality the instrument measured the husk's resistance to penetration which was considered to parallel the difficulty a rat would experience when attacking a green coconut.

To assess husk resistance to penetration, 66 palms with a history of either a low or high level of damage were selected from three survey sites (Maravu Hill one and two and Salt Lake; Section 3.3B). Nuts from bunches six and seven, aged five to six months were penetration tested (n = 132 coconuts). The measurements were made at the same site on all coconuts. Of the nuts tested 72 were from palms that had incurred little damage over the three years of survey while 60 were from palms that had, on average, lost over 10 nuts per palm per year. A comparison of the mean penetration distance of the two groups revealed that nuts from high damage palms were significantly easier to

FIGURE 3.6

THE INSTRUMENT THAT WAS USED TO MEASURE HUSK HARDNESS

Operation described in the text



penetrate than those from the low damage group ($t = 2.08$, $p > 0.025$). Mean penetration depths were 19.3 mm (high) and 16.9 mm (low), which while being significantly different were not of a magnitude that rats might be expected to consistently differentiate. However, the selection of the sample nuts from bunches delimited according to their relative position on the palm in relation to the youngest bunch, introduced a considerable amount of variability. While a bunch's relative position approximated its age there was substantial variation from palm to palm and thus in husk hardness, which increased with age (see below). If nuts of exactly the same age could have been selected from all palms surveyed, the difference between the means of the two groups would probably have been greater.

Despite these qualifications it appears that rats are favouring coconuts that are softer. However it could be postulated that nut selection by rats is the result of the combined influence of sugar concentrations and husk hardness, because rats do not concentrate their attack on the very smallest, and therefore softest, nuts, but favour those aged four to six months and known to have the highest sugar levels. During the period when sugar concentrations are at a peak the husk of the developing coconut is rapidly becoming much harder, as illustrated by the difference between the penetration depths of five and six month old nuts; 22.0 mm and 15.2 mm respectively. Such variations in hardness, which would make attack easier, may be detected and utilised by some rats.

While sugar levels and husk hardness were being investigated it was decided to compare the levels of critical nutrient elements, such as nitrogen, phosphorus and potassium, in developing coconuts from palms that incurred a high or low level of damage. Samples were collected from bunches five to seven on 71 palms at three survey sites (Maravu Hill one and two and Salt Lake) and analysed by the Chemistry Division for N,P,K,Ca, Mg and Na levels. Each sample was taken one third of the distance along the coconut from the attachment point and consisted of a 2 cm diameter section through the developing husk, shell and endosperm. Nitrogen was the only element that different significantly between the high and low damage groups; 0.63 percent and 0.46 percent respectively ($t = 3.9$, $p > 0.01$).

The significance of this difference in N levels is difficult to determine as most animal's food intake is governed by the energy value of the food rather than by qualities such as protein content. Higher nitrogen levels in the favoured nuts indicate the presence of more protein but there is no evidence that rats can select for protein per se. Ashchkensay-Lela (1946) and Scott and Quint (1946), cited in Barnett (1963) found that protein deficient albino rats could not effectively choose between diets with high and low levels of protein. Although rats do not seem to be able to select for protein there are other individual substances which, because of their nutritional value, can influence food choice. Such behaviour is sometimes called 'dietary self selection' and Barnett (1963) cites several examples of rat's ability to select diets containing vitamins (i.e. B), or inorganic salts (NaCl) when such substances are deficient in other sources of food.

The selection of advantageous diets by mammals, including man, is a general phenomena and depends largely on rapidly learning the favourable effects of particular foods: it is also known that some foods are consumed in greater quantities than required. For example, Garrison and Breidstein (1970) found that rats attacking sugar cane utilised only half the actual sugar in the cane stalk material consumed. They concluded, in view of rats known preference for sweet substances that sugar cane constituted a 'luxury' food and not a primary food. This conclusion almost certainly applies to rat attack of coconuts for even in areas of short palms (Salt Lake) where the foraging of R. exulans includes some palm crowns, the level of damage over several years did not bear a close relationship to the number of rats present (2.5C), with the numbers of nuts damaged per day clearly providing only a small percentage of the rat population's food requirements. It is probable, particularly in view of rat attack behaviour in cocoa (Chapter 5), that only some members of the rat population foraging in palm crowns attack coconuts and that even for these animals it is not an important source of food.

While the presence of sugars in the developing nut appears to be attractive to rats, the motivation to attack the sweetest stage cannot be particularly high since the hardness of some developing coconuts appears to deter attack even though rats gnaw holes through much harder materials. This possible lack of a high level of motivation could be due to nutritional deficiencies of the coconut material. Strecker and Jackson (1962) found that R. exulans and R. rattus lost weight on a diet of only coconut kernel despite it having an energy value of 359 calories per 100 g (Sherman, 1952). This was more than double R. norvegicus minimum energy requirements of 139 calories per 100 g (Schein and Orgain, 1953).

To conclude, it is certainly evident that many factors could influence rat attack of coconuts and that the relative importance of each factor will differ from one habitat to another. However the above results do suggest that, while green coconuts are not a major food source for the whole population, various numbers are attacked at the developmental stages containing the highest concentration of sugars with rats showing an apparent preference for nuts with softer husks.

3.3 DAMAGE ASSESSMENT

3.3A DEFINITION OF TERMS

Generally crop loss can best be measured by comparing the yield of pest controlled and untreated plots. Such an approach is impractical with a highly mobile pest such as the rat, as it would require plots so large that adequate surveys of different sites over a number of years would be too costly. This problem was overcome by recording variations in damage symptoms, e.g. coconuts holed by rats, while determining the relationship of this symptom to yield loss.

Where the pest attacks and destroys the fruit the relationship may be simple; that is, the percentage of fruit attacked equals the percentage of crop lost. Sometimes this appears so obvious, e.g. when the fruit is attacked just prior to harvest, as with rat attack of cocoa (Chapter 5), that the relationship is assumed without experimental verification. When the fruit is attacked some months before harvest, as in rat attack of coconuts, a simple relationship between the measure of damage and reduction in yield may not exist, but by inducing known levels of rat damage and measuring the resulting coconut yields, as described in 3.4C, the nature of the relationship may be determined.

In the field of crop damage assessment there is frequently some confusion over terms such as "damage", "loss" etc. In these results "damage"will refer only to the attacked immature coconuts, while "loss" will refer to the actual reduction in yield (harvestable coconuts) caused by rats.

3.3B DAMAGE SURVEYS

I. Methods

Two methods of damage survey were established. The first consisted of long term (six months to three years) monitoring, on Vanua Levu and Taveuni, of rat damaged and harvestable nutfall at 16 sites that represented a range of palm ages and levels of grove management. (Figures 1.8, 1.9 3.7 and 3.8). As regular visits to the sites were essential these were chosen in accessible places, adjacent to a road or farm track. The locations were all in Cakaudrove (S.E. Vanua Levu and Taveuni), as this area produces 50-60 percent of Fiji's total copra production (Table 1.2) and Paine's (1934) survey indicated that damage here could be severe. Table 3.2 summarises the major features of the survey sites.

At each site all trees were numbered and the property owner requested to leave nut collection to the survey team. Nuts were gathered on the ground only. A power-slasher was used to control undergrowth at only one site (Tuvamaca) and as slashing was done immediately after nut collection this caused little scattering of nuts.

Coconuts from most plots were collected at fortnightly intervals, graded into five cm size classes and recorded in the following categories:-

1. Fresh rat damage; green coconuts with decay at an early stage (Type 1 damage).
2. Old rat damage; Brown or dry coconuts often with the decay at an advanced stage as nuts take up to two years to rot sufficiently to break up (Type II damage).
3. No rat damage; Fresh green coconuts, a category which in effect includes all other forms of immature nutfall.

FIGURE 3.7

GENERAL VIEWS OF TWO LONG TERM SURVEY PLOTS

Top = Maravu coastal Plot 1 (A)
Bottom = Nagigi overgrown Plot (B)

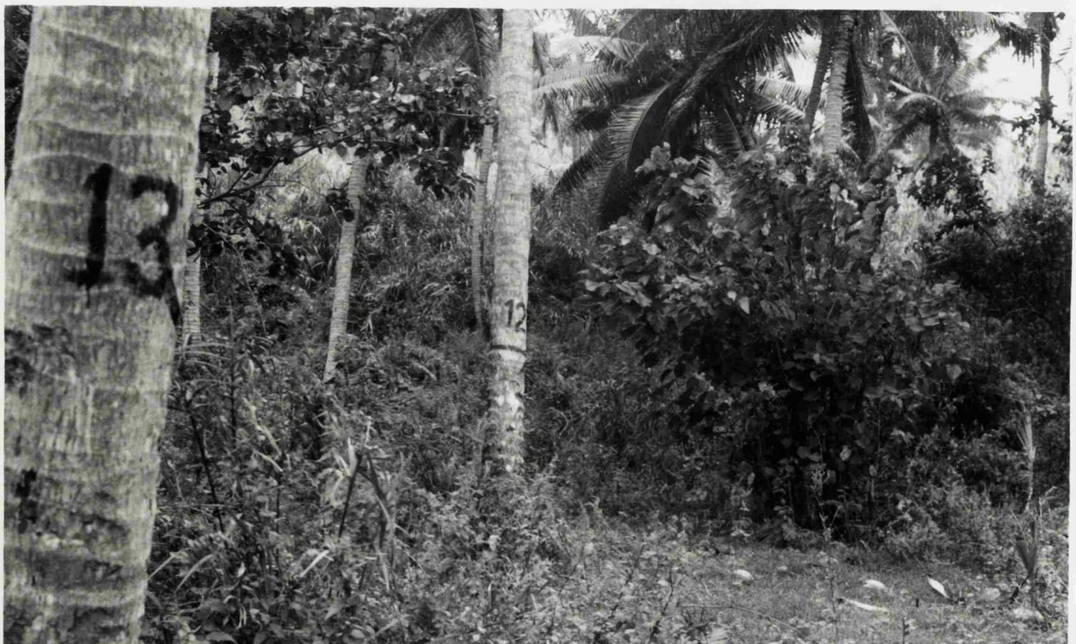

13
12

FIGURE 3.8

THE LOCATION OF LONG TERM SURVEY SITES ON S.W. VANUA LEVU AND TAVEUNI

A = Matanakavika

B = Maravu Coastal 1

C = " " 2

D = " Hill 1

E = " " 2

F = Nabaka

G = Nagigi

H = Kubunu

I = Salt Lake

J = Levuka Lailai 1, 2 and 3

K = Vunilagi 1 and 2

L = Tuvamaca

M = Wainiyaku

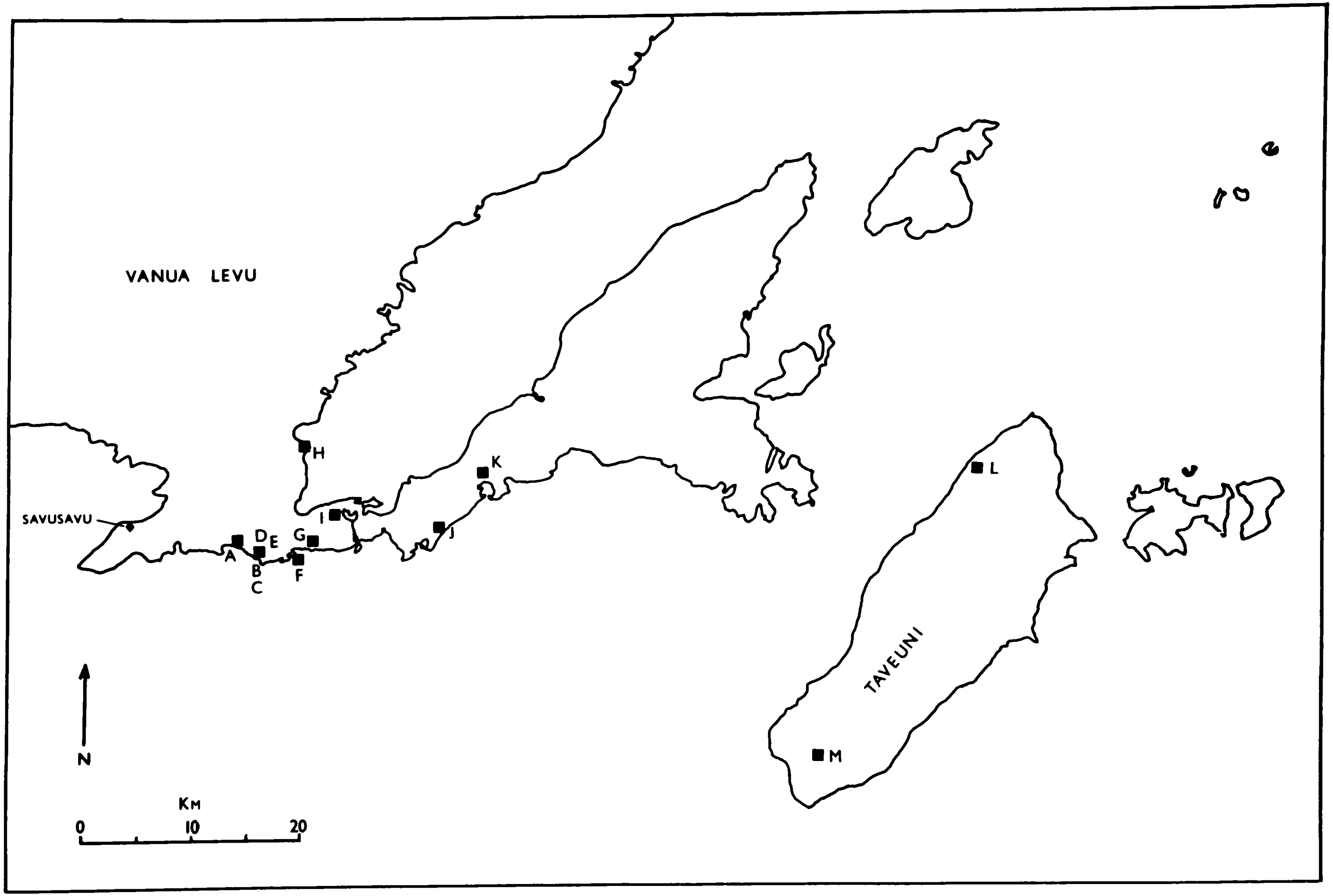

VANUA LEVU
SAVUSAVU
A
B
C
D
E
F
G
H
I
J
K
L
M
TAVEUNI
N
KM
0
10
20

Table 3.2 A SUMMARY OF THE MAJOR FEATURES OF THE LONG TERM COCONUT SURVEY PLOTS

Site	Plot No.	Palms Height (metres)	Area of* Plot (ha)	No. of Palms (per ha)	Topograph and usual Ground cover
Matanakavika	1	21-24.5	0.61	100 (165)	Flat coastal site - just cleared of heavy undergrowth
Maravu	1 coast	12-24.5	0.24	50 (208)	Flat coastal site adjacent to beach - grazed grass
	2 coast	12-18	0.76	100 (134)	Flat coastal site, grazed but weed cover at some seasons
	1 Hill	6-10.5	0.75	100 (136)	Moderate uniform hill slope area, grazed, few weeds
	2 Hill	6-10.5	1.01	100 (100)	Basin shaped area flat plus mounds; bordered by bush patches, seasonal weeds
Nabaka	1	18.5-21.5	0.19	40 (232)	On coastal headland, very heavy undergrowth to six metres
Nagigi	1	15.5-18.5	0.26	40 (154)	Inland on hill slope, wet area tall reeds and weed ground cover
Kuhunu	1	15.5-18.5	0.17	40 (236)	Coastal flats, Natewa bay, reed and weed cover plus light bush; some grazing
Salt Lake	1	6-9	0.42	60 (143)	Inland gully flat, scattered citrus undergrowth, seasonal weed cover heavy, some grazing
Levuka Lailai	1	18.5-21.5	0.50	100 (200)	All plots on coastal flats No. 1 adjoining beach,
	2	15.5-24.5	0.41	100 (246)	No. 2 0.4 Km inland and
	3	18.5-24.5	0.53	100 (190)	No. 3 at hill base All grazed-ground cover light
Vunilagi	1	15.5-18.5	0.57	50 (88)	Plot 1 on inland flat,
	2	15.5-18.5	0.57	50 (88)	Plot 2 on adjacent hill slope area grazed but heavy sedge and weed cover plus some guavs
Tuvamaca	1	7.5-10.5	0.57	120 (210)	On a coastal hill spur, moderate slope, heavy grass and weed cover, grazed
Wainiyaka	1	4.5-7.5	1.09	120 (110)	Inland, southern Taveuni 185 m above sea level. Grass cover-grazed

* Area is the total encompassed by the plot and includes all gaps in plantings.

4. Harvestable; coconuts normally cut for copra

5. Others; this consists mostly of mature barren nuts.

Damage was recorded on an individual palm basis for all plots, while harvestable nuts were recorded for the plot as a whole, except Salt Lake where each palm was recorded separately. At each recording all nuts were removed from the plot. In 1972, two counts were made of the standing crop (i.e. all nuts on the palm over three months old) on all palms in survey plots. The mean of such counts approximated to a year's production (Smith pers. comm. Jamaican Coconut Industry Board Method of Coconut Recording).

The second type of survey consisted of counting all rat damaged nuts, on one occasion, at a series of representative sites. Counts were usually made for each palm with a minimum of 25 palms being recorded at any one site. Damaged coconuts were recorded as with fresh rat damage or with old rat damage. These counts were then correlated with knowledge of the decay rates of rat damage coconuts and used as a measure of damage over a longer period.

II. Results

a) Long Term Assessment

i) Damage levels and distribution through time and space.

Seasonal and annual trends:

A summary, on an annual basis, of all long term damage and production data from the 16 sites (1270 palms) gave an overall picture of damage levels and the variations between sites (Tables 3.3, 3.4, 3.5 and 3.6). In these tables the damage category included types I and II as defined above. Rat damaged and harvestable nuts have been expressed as nuts/palm/year and nuts/hectare/year for this is the most meaningful representation. Since other workers (Taylor, 1930; Paine, 1934; Smith, 1969)

Table 3.3 PRODUCTION AND DAMAGE OF COCONUTS ON VANUA LEVU BETWEEN OCTOBER 1969 AND DECEMBER 1970

Plot site and No. of palms	Rat damaged nuts (X)	Harvested nuts (Y)	Rat damaged		Harvested		Rat damaged nuts as a % of X + Y	Months recorded
			Nuts/palm/year	Nuts/Hect/year	Nuts/palm/year	Nuts/Hect/year		
Maravu								
Coastal 1 (50)	302	1938	5.4	1134	34.2	7183	13.5	13.5
Coastal 2(100)	320	5551	3.2	427	48.2	6432	5.4	11.7
Hill 1 (100)	729	5101	6.4	857	45.2	6032	12.5	13.5
Hill 2 (100)	984	5431	8.7	860	48.0	4744	15.3	13.5
Matanakavika								
Coastal 1 (100)	146	2891	2.3	380	45.9	7598	4.8	7.6
Salt Lake (6)	498	2636	7.5	1075	39.6	5676	15.8	13.3
Levuka Lailai								
Plot 1 (100)	58	2410	0.5	99	21.6	4324	0.2	13.5
Plot 2 (100)	638	3016	5.7	1408	28.2	6968	17.5	13.5
Plot 3 (100)	1031	5702	9.2	1749	50.8	9664	15.3	13.5
Vunilagi								
Plot 1 (50)	297	2212	5.2	462	40.0	3558	11.8	13.5
Plot 2 (50)	182	2047	3.2	284	36.6	3254	8.2	13.5

Table 3.4 PRODUCTION AND DAMAGE OF COCONUTS ON VANUA LEVU BETWEEN DECEMBER 1970 and DECEMBER 1971

Plot site and No. of palms	Rat damaged nuts (X)	Harvested nuts (Y)	Rat damaged		Harvested		Rat damaged nuts as a % of X + Y	Months recorded
			Nuts/ palm/ year	Nuts/ Hect/ year	Nuts/ palm/ year	Nuts/ Hect/ year		
Maravu								
Coastal 1 (50)	90	1842	1.8	378	36.8	7729	4.6	12.0
Hill 1 (100)	221	4701	2.2	294	47.0	6271	4.3	12.0
Hill 2 (100)	913	5092	9.1	899	50.9	5031	15.4	12.0
Nabaka (40)	221	2044	6.7	1458	56.5	12285	9.8	11.8
Nagigi (40)	7	1502	0.2	30	41.5	6358	0.5	11.8
Kubunu (40)	16	1942	0.4	91	54.8	12592	0.8	10.6
Salt Lake (60)	277	2723	4.6	660	45.4	6506	9.2	12.0
Levuka Lailai								
Plot 1 (100)	1	2021	0	0	20.2	4042	Nil	12.0
Plot 2 (100)	249	2725	2.5	499	27.2	6721	8.4	12.0
Plot 3 (100)	158	5215	1.6	304	52.1	9914	2.9	12.0
Vunilagi								
Plot 1 (50)	324	1622	6.5	578	32.4	2881	16.6	12.0
Plot 2 (50)	332	1727	6.6	588	34.5	3069	16.1	12.0

Table 3.5 PRODUCTION AND DAMAGE OF COCONUTS ON VANUA LEVU BETWEEN DECEMBER 1971 AND AUGUST 1972.

Plot site and No. of palms	Rat damaged (X)	Harvested nuts (Y)	Rat damaged		Harvested		Rat damaged nuts as a % of X + Y	Months recorded
			Nuts/ palm/ year	Nuts/ Hect/ year	Nuts/ palm/ year	Nuts/ Hect/ year		
Maravu								
Coastal 1 (50)	289	959	8.3	1742	28.0	5881	23.2	8.3
Hill 1 (100)	113	3284	1.6	212	43.8	5844	3.3	8.3
Hill 2 (100)	393	3084	5.7	563	44.0	4349	11.3	8.3
Nabaka (40)	63	1552	2.3	499	55.4	12046	2.6	8.2
Nagigi (40)	2	1612	0.1	15	54.0	8273	0.1	8.2
Kubunu (40)	9	1570	0.3	47	56.0	12869	0.6	8.3
Salt Lake (60)	165	1764	3.4	487	38.5	5518	8.6	9.7
Levuka Lailai								
Plot 1 (100)	0	1957	0	0	28.8	5762	0	8.3
Plot 2 (100)	38	2462	0.6	148	36.2	8945	1.5	8.3
Plot 3 (100)	138	3903	2.0	381	57.4	10922	3.4	8.3
Vunilagi								
Plot 1 (50)	109	2052+	3.2	284	41.0	3647	N.A.	8.3
Plot 2 (50)	135	1894+	3.9	346	37.8	3663	N.A.	8.3

Table 3.6 PRODUCTION AND DAMAGE OF COCONUTS ON THE ISLAND OF TAVEUNI FOR YEARS 1971 AND 1972

Plot site and No. of palms	Rat damaged (X)	Harvested nuts (Y)	Rat damaged		Harvested		Rat damaged nuts as a % of X + Y	Months recorded
			Nuts/palm/year	Nuts/Hect/year	Nuts/palm/year	Nuts/Hect/year		
Tuvumaca Estate								
1971								
Plot 1 (120)	721	4264	6.0	1275	35.5	7544	14.5	11.4
1972								
Plot 1 (120	501	3434	5.4	1146	36.8	7821	12.7	9.3
Wainiyaku Estate								
1971								
Plot 1 (120)	738	N.R.*	6.2	-	-	-	-	11.4
1972								
Plot 1 (120)	761	N.R.	8.2	-	-	-	-	9.3

* N.R. = Not recorded.

have expressed damage as a percentage of total production this measure was also provided for comparisons, but these can only be valid when harvestable production is similar.

There was clearly a big variation in damage from site to site ranging from 0.5 to 9.2 nuts/palm/year in 1970 (Table 3.3) and zero to over 8 nuts/palm/year in 1971 and 1972. (Tables 3.4, 3.5, 3.6). The level of damage per hectare was dependent on palm density as well as the level of damage per palm. The highest losses per hectare occurred mostly on plots with over 200 palms per hectare (e.g. Levuka Lailai Plot 2 and 3; Nabaka, and Maravu Coastal Plot 1). However some high density plots had very low levels of damage (e.g. Kubunu and Levuka Lailai Plot 1), so damage was not necessarily related to palm density at least in areas where palm height exceeded 15 m. The notable variation in damage between plots was due partly to the effect of palm height (discussed below) but there were also big differences in the level of damage between plots in plantations where ground habitat and palm height were fairly uniform; i.e. Levuka Lailai plots and Maravu plots (Table 3.2).

A difference in rat numbers at the various sites could have accounted for the variations in damage except that the three Levuka Lailai and the four Maravu plots were relatively close to each other (less than 0.5 km apart; Figure 3.8), and there was a poor correlation between rat numbers and the level of damage at Salt Lake (Section 2.5C). Populations of R. rattus that consistently attacked coconuts in one locality could also have accounted for the differences but none of the data collected supported this explanation. A reduction in the availability of major items in Rattus diets could also affect damage levels by prompting these species to eat more coconuts, which are probably only a "luxury" component of the diet.

Seasonal fluctuations in damage were apparent on a few plots (Figure 3.9A and B), and consisted of a rise in damage during the periods when there was an increase in the favoured size classes of nuts; i.e. approximately six months prior to the seasonal peaks in harvestable nuts. For example, the harvestable coconut peaks in Figure 3.9B were adjusted back six months in time to indicate when peaks of favoured immature nuts occurred. These then correlated ($r = +0.52$, $p => 0.01$) with the level of damage. However, this trend was not evident on most plots and may become apparent only at the highest recorded levels of damage when the coconuts most favoured by rats are possibly available in only limited numbers.

A marked long term change in damage occurred at Levuka Lailai Plot 3 (Figure 3.9D) with annual damage dropping from an average of 9.2 nuts/palm/year in 1970 to 1.2 and 2.0 nuts/palm/year in 1971 and 1972. This decrease in level of damage took place without any obvious changes in plantation habitat or known major changes in the rat populations. Trapping in the plot during November 1971 established that both R. rattus and R. exulans were still present and while there may have been changes in the R. rattus population (the attacking species at the site) the Salt Lake population study revealed that such changes may not be reflected in damage levels (Section 2.5C).

Spacial distribution and selective attack: The spacial distribution of damage and variations in level from palm to palm within a plot were also notable features of rat damage to coconuts (Figure 3.10) for they indicated that attack was selective. In most plots damage was confined to a limited number of palms located at random throughout the plot; randomness was tested by applying Runs Test (Sokal and Rohlf, 1969) to the accumulated damage for each palm listed according to the number assigned when the plot was established (Salt Lake, $t_s = 1.1$; Vunilagi Plot 1,

FIGURE 3.9

MONTHLY TOTALS OF RAT DAMAGE AND PRODUCTION ON FOUR SURVEY PLOTS FOR YEARS 1969-1972.

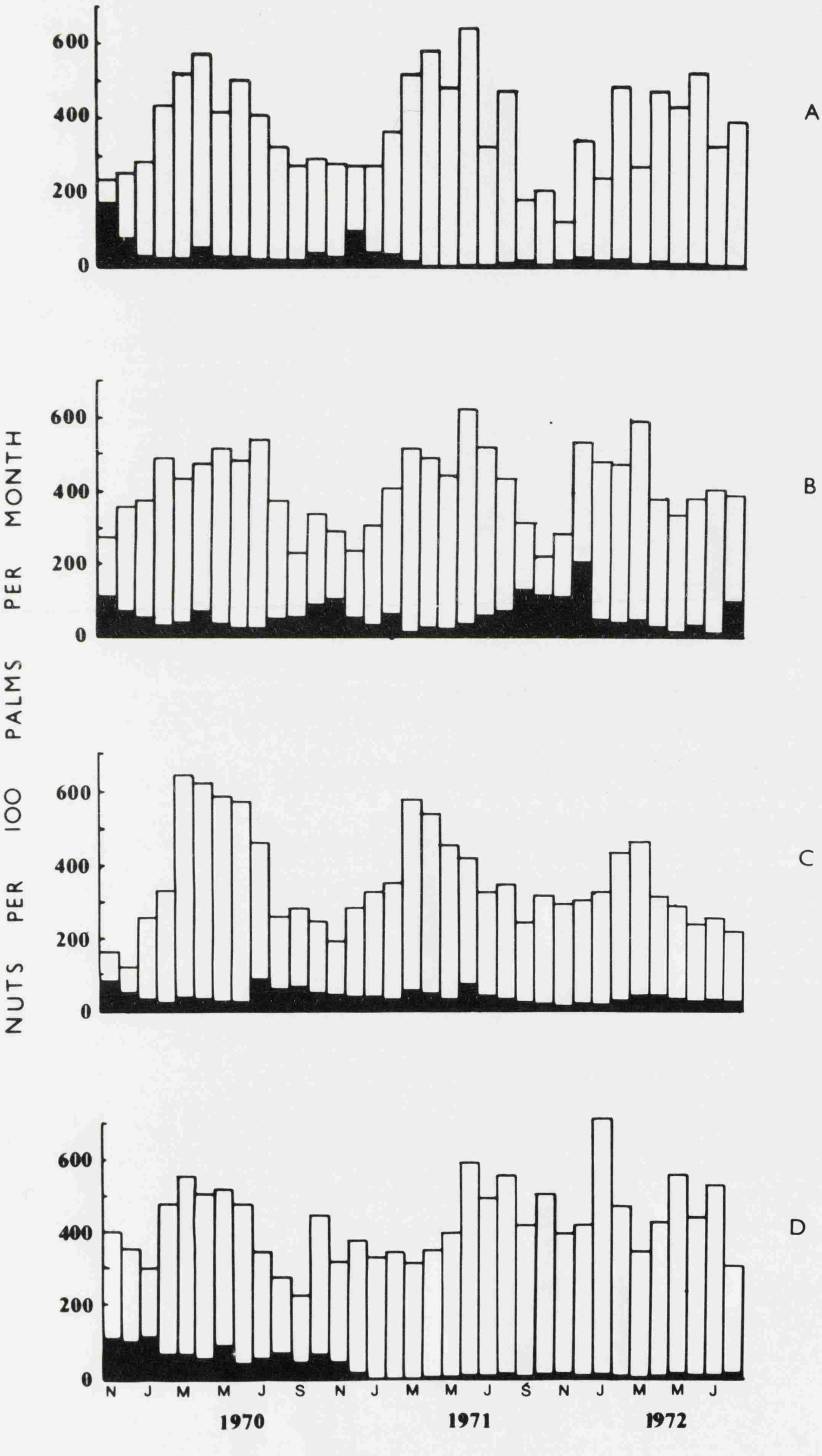
A = Maravu Hill Plot 1

B = Maravu Hill Plot 2

C = Salt Lake Plot

D = Levuku Lailai Plot 3

Total height of histogram represents harvestable nuts, black represents type I and II rat damage (see text).



NUTS PER 100 PALMS PER MONTH
600
400
200
0
A
B
C
D
N J M M J S N J M M J S N J M M J
1970
1971
1972

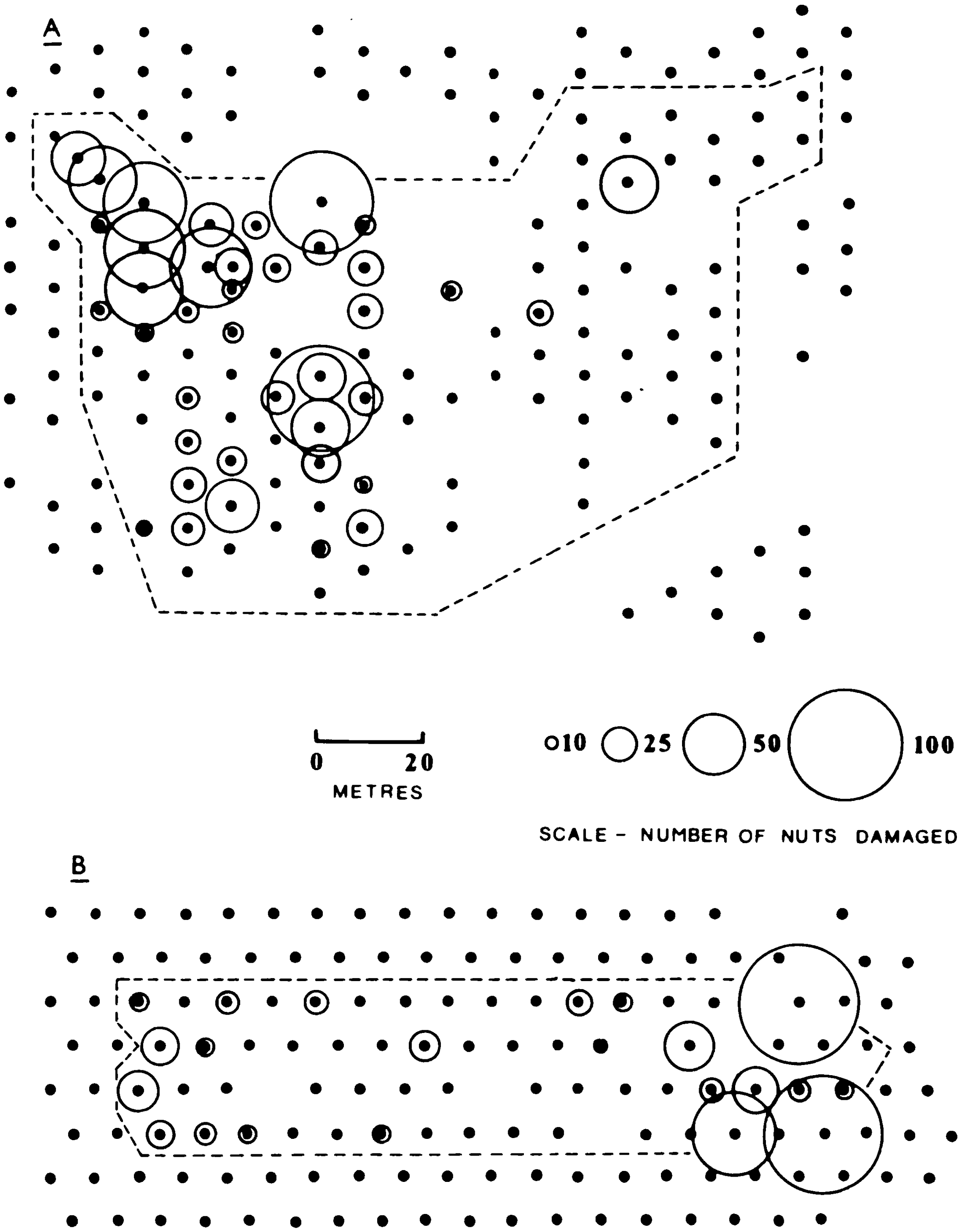
FIGURE 3.10

SPACIAL DISTRIBUTION OF DAMAGE ON TWO SURVEY PLOTS

A = Maravu Hill Plot 2

B = Salt Lake, Plot

These data, for 1970 and 1971, include only palms that lost more than 10 nuts during the two years. Circle size indicates the number of nuts damaged and dots the position of each palm. Broken lines indicate survey plot limits.


A
0 20
METRES
10 25 50 100
SCALE - NUMBER OF NUTS DAMAGED
B

$t_s = 0.2$; Plot 2, $t_s = 1.7$; Maravu Hill Plot 1, $t_s = 0.6$; Levuka Lailai Plot 2, $t_s = 1.9$; Plot 3, $t_s = 1.0$; where t_s of 1.96 = significant departure from random distribution (at the 5% level). Non-random distribution of damage was evident only within Maravu Hill Plot 2 (Figure 3.10, $t_s = 4.2$). Although favoured palms were seldom clumped, total damage for each plot was confined to a limited number of palms and in most plots over 75 percent of the nuts damaged came from less than 30 percent of the palms. This distribution of damage was a manifestation of the rats apparent ability to select the softest nuts at a stage when sugar concentrations were highest (Section 3. 2C).

Of particular importance was the effect that selective attack had on the production of the affected palms. A comparison between the number of harvestable nuts produced by palms consistently attacked over three years with production from those seldom attacked showed no significant difference at three survey sites (Tables 3.7, 3.8A and 3.8B; $t = 1.3$, 0.8 and 1.5 respectively). At Salt Lake (Table 3.7) damage per palm averaged 16.5 nuts/palm/year for the high damage group and less than 1 nut/palm/year for the low damage group. The effect this marked concentration of damage has on production of harvestable nuts is illustrated in Figure 3.11A. For example, 30 percent of the palms produced 37 percent of the harvestable nuts, despite damage amounting to 83 percent of the plot gross total. This comparison was based on nut number, not kernel yield per nut; a comparison between kernel yield per nut from high and low damage groups indicated no significant difference (318 g and 315 g per nut respectively, $n = 100$).

The apparent absence of an effect at quite high levels of damage, i.e. 10-18 nuts/palm/year, on the production of

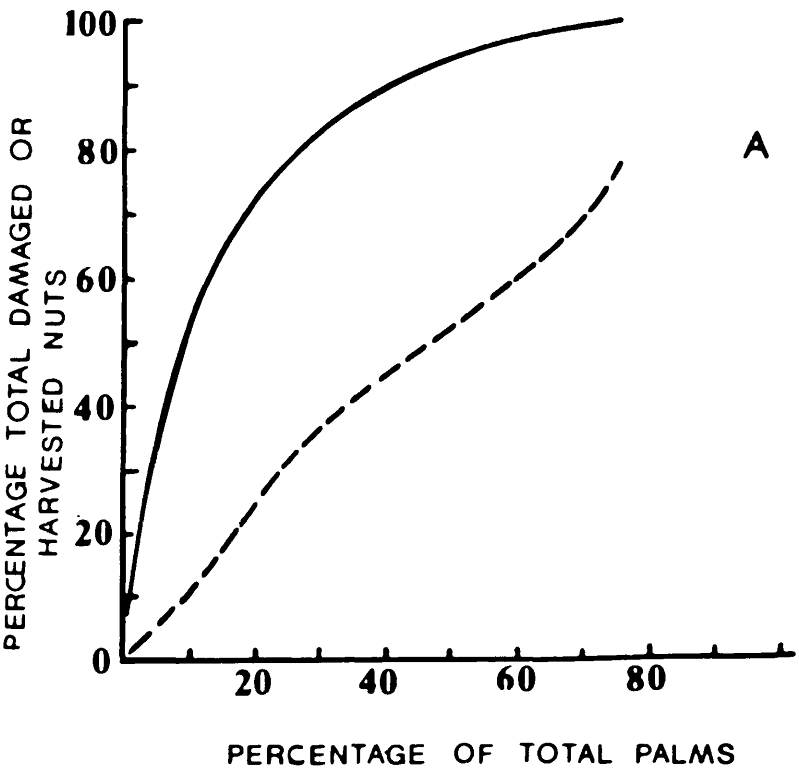
FIGURE 3.11

THE EFFECT OF SELECTIVE RAT ATTACK ON THE NUMBER OF HARVESTABLE COCONUTS PRODUCED

A. Salt Lake Plot, data for 1970

B. Vunilagi, Plots 1 and 2 for 1972

Solid line represents the number of coconuts damaged, the broken line the number of coconuts harvested.


A
PERCENTAGE TOTAL DAMAGED OR HARVESTED NUTS
PERCENTAGE OF TOTAL PALMS
0
20
40
60
80
100

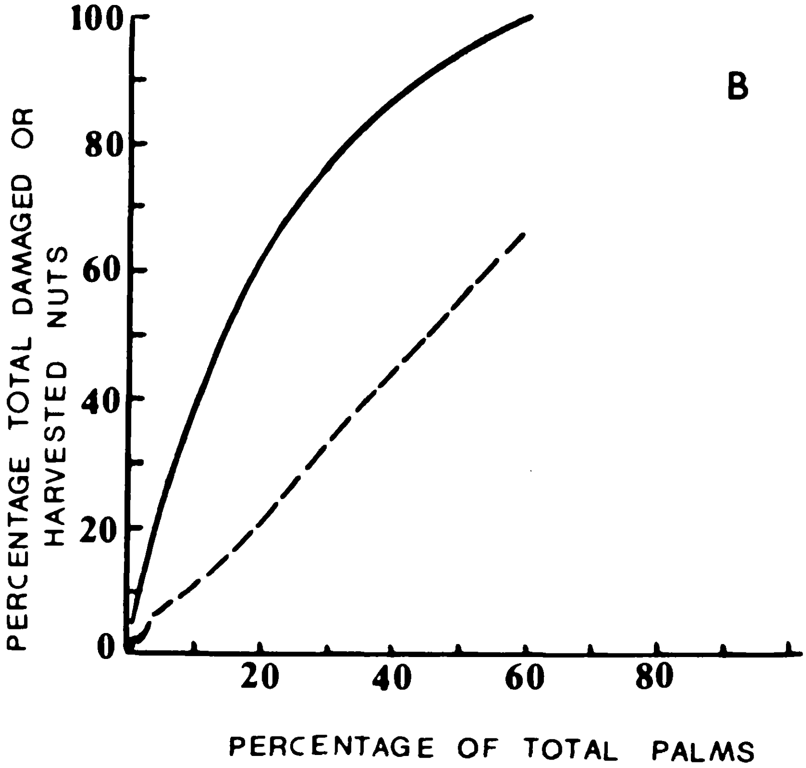

B
PERCENTAGE TOTAL DAMAGED OR HARVESTED NUTS
PERCENTAGE OF TOTAL PALMS
0
20
40
60
80
100

Table 3.7 DAMAGE LEVELS AND THE EFFECT ON PRODUCTION: A comparison based on 11 palms incurring a <u>high</u> level and 13 a <u>low</u> level of damage within the 60 palm Salt Lake Survey plot.

	1970				1971				1972			
	Rat damaged		Harvested		Rat damaged		Harvested		Rat damaged		Harvested	
	High	Low	High	Low	High	Low	High	Low	High	Low	High	Low
Total nuts damaged or harvested	219	0	522	541	194	13	550	535	132	5	517	529
No. damaged or harvested per palm	19.9	0	47.4	41.6	17.6	1.0	50.0	41.1	12.0	0.4	47.0	40.7
Total No. damaged or harvested for all palms in the plot	319		2648		277		2725		175		2476	
Percentage of the total damaged and harvested accured by the palms in each category.	68.6	0	19.7	20.4	70.0	4.7	20.2	19.6	75.4	2.9	20.9	21.4

Table 3.8 DAMAGE LEVELS AND EFFECT ON PRODUCTION

A. A comparison based on 25 palms incurring a high level and 25 a low level of damage within the 100 palm Maravu Hill Plot 2.

	HIGH DAMAGE		LOW DAMAGE	
	Rat damaged (1970-1972)	Estimated No.* harvestable	Rat damaged (1970-1972)	Estimated No.* harvestable
Total nuts damaged or harvested	1413	1014	14	905
Mean No. damaged or harvested per palm	56.5	40.6	0.6	36.2
S.E. of Mean	4.9	3.8	-	3.5

* Harvestable production estimated for 1972 on the basis of two counts of the standing crop on the palm.

B. A comparison based on 20 palms incurring a high level and 20 a low level of damage within the 100 palms in Vunilagi Plots 1 and 2.

	HIGH DAMAGE		LOW DAMAGE	
	Rat damaged (1970-1972)	Estimated No.* harvestable	Rat damaged (1970-1972)	Estimated No.* harvestable
Total nuts damaged or harvested	638	866	61	741
Mean No. damaged or harvested per palm	31.9	43.3	3.1	37.0
S.E. of mean	3.7	3.1	-	2.9

* Note as above

harvestable nuts, was a feature of major significance as it suggested that rats were not causing a reduction in overall yield. However, palms incurring high levels of damage may have been more vigorous types that, in the absence of selective attack, would have produced more copra than those incurring little damage.

ii) The relationship between palm height and rat damage

A comparison of damage sustained by the nuts on short and tall palms during 1971 showed that significantly more nuts were damaged on short palms (Table 3.9; $t = 2.34$, $p > 0.05$). While nuts on short palms may have been generally more attractive to rats, the higher level of damage was more likely due to the greater numbers of Rattus foraging in such palm crowns. In effect, coconuts on short palms were at risk to a greater proportion of the total rat population since, as palms were seldom inhabited during the day (Section 2.4C), short palms were probably climbed more regularly by R. rattus and were probably the only ones climbed by R. exulans.

This effect of height on damage could account for the large estimates of damage (23 nuts/palm/year) obtained by Paine (1934) on Taveuni. Over a period of four months he recorded damage on palms typical of that time, that is only 20-30 years old and probably less than 12 m high. However, as shown in Figure 3.9D, an estimate based on a short recording period at one site (i.e. any four month period in 1970 compared with a similar period in 1971 or 1972) could give a false estimate of long term damage levels.

iii) The relationship between ground vegetation and rat damage.

Although clearing of undergrowth in plantations and the maintenance of a weedfree environment has been cited as a method of reducing rat damage in coconuts (Wodzicki, 1968; Sproat , 1966), ground cover appeared to have little consistent effect on damage

Table 3.9 A COMPARISON BETWEEN THE NUMBER OF COCONUTS DAMAGED ON SHORT AND TALL FIJI TALL PALMS DURING 1971

(All Long term survey plots)

	Short palms (under 10 metres)	Tall palms (over 15 metres)
No. of plots	9	9
No. of plot sites	5	9
Total No. of palms	500	570
No. of nuts rat damaged	2756	1398
Mean No. of rat damaged nuts per palm per year	5.5 ± 0.7	2.8 ± 0.9

levels during this study.

Three of the survey sites (Nabaka, Kubunu and Nagigi) were overgrown (Table 3.2 and Figures 1.9 and 3.7B) while three of the others were moderately so; ie. they had tall grass, weeds and guava or citrus most of the year (Table 3.2 and Figure 2.3). A comparison between the 1971 and 1972 damage levels on these six plots with those on all survey plots, which were relatively weedfree throughout the year (Figure 3.7A) suggests that the amount of undergrowth did not affect damage levels. During the two years, overgrown plots recorded an average damage level of 3.2 $\pm$0.7 nuts/palm/year and in clean plots 4.1 $\pm$0.8 nuts/palm/year. The effect of plantation habitat on damage levels is undoubtedly complex and while for many reasons plantations should be kept relatively free of undergrowth it will clearly not guarantee low levels of rat damage.

iv) Summary of long term assessment.

The overall level of damage on all plots on Vanua Levu and Taveuni over the three years was:-

Year	No. of palms	Average density per hectare	Damage levels/year nuts/palm	nuts/ha	Percentage damaged
1970	910	155	5.4 $\pm$ 0.45	840	13.3
1971	1070	174	3.9 $\pm$ 0.31	680	8.4
1972	1070	174	2.5 $\pm$ 0.23	435	5.6

These data indicate a much lower overall level of damage then Paine's (1934) oft quoted figure for Fiji of 28 percent (23 nuts/palm/year), although the marked drop in damage between 1970 and 1972 does suggest that levels fluctuate considerably.

III Single sample assessment of damage

a) Decay characteristics

A rapid method of assessing the number of nuts damaged by rats must be available if rat control is to be a viable aspect of coconut crop protection. Farmers clearly cannot carry out long term surveys to determine damage levels. In an attempt to develop a rapid method of estimating the level of rat damage, the decay rate of damaged nuts was investigated, to determine how long coconuts remained on the palm after being attacked and the time they took to rot after falling from the palm. It was hoped that such information on the life of damaged nuts would enable single counts (spot surveys) to be expressed as damage over a particular period of time. The decay of rat damaged coconuts can be divided into two categories, both with identifiable endpoints. The first category covers the period, immediately after attack, during which the nut changes in colour from green to brown (Type I damage, Section 3.3B). The second category of decay corresponds to the whole period from attack to the ultimate collapse of the husk as the nut rots away on the ground (Type I + Type II damage, Section 3.3B).

The time lapse during the first phase of decay was investigated by puncturing a representative sample (i.e. nuts aged three to seven months, n = 234) of green coconuts and placing them in the partial shade of 12 year old palms during September 1970. The time taken for each nut to turn completely brown was recorded and found to be 39 $\pm$ 0.4 days, under rainfall conditions that were drier than average for the south-west coast of Vanua Levu (i.e. only 165 mm of rain during the 40 days; Section 1.2).

The total decay period, from initial attack to final decay, was investigated using 58 Fiji Tall and 57 Malayan Dwarf coconuts. After two years all the coconuts, which had been also kept in a weedfree area under the partial shade of 12 year old coconut palms, could be crushed in one hand, a feature considered an acceptable endpoint for total decay.

The interval between rat attack of a nut in the palm crown and detachment from the inflorescence was also investigated, as this affects the estimated time lapse for the colour change in damaged nuts collected on the ground. Attack on the size classes of nuts favoured by rats, on palms 45 years old, was simulated using a 2 cm diameter steel cork borer. Detachment time was found to be 4.5 $\pm$ 0.2 days (n = 130). Some nuts aged two to three months detached only two days after attack while those aged from five to six months took up to seven days, The above trials were repeated in Tonga (Pierce, 1971) and it was found that the average time taken to turn from green to brown was 41 $\pm$ 0.8 days (n = 816) and the time lapse between attack and detachment 4.7 $\pm$ 0.3 days, figures which are very similar to those obtained in Fiji, suggesting that variations in normal weather conditions had minimal influence on the rate of decay.

When the decay rate trials were begun in early 1970 it was hoped that the first phase of decay (the colour change) would provide the best basis (index) for estimating the amount of rat damage over longer periods. A trial aimed at investigating the accuracy of damage predictions, based on the number of nuts recorded as being within the first decay category, indicated that predictions for periods of only three months differed by an average of 50.0$\pm$ 7.4 percent from actual damage (32 projections on three sites, with a total of 150 palms). A discrepancy of this magnitude might have been expected at most sites in view of the variations in damage that were observed from month to month and season to season (Figure 3.9).

Because of the large number of variables, spot counts of green damaged coconuts could not accurately predict damage. However, such counts did give an accurate estimate of the damage that had occurred over the immediate past 33-35 days (i.e. 39 days less the average detachment time of 4.5 days).

A count of damaged nuts, in both decay categories, did not represent two years accumulation as suggested by the static trial described above. Under average plantation conditions a proportion of the damaged nuts were destroyed by cattle, weeding and burning operations before they had rotted normally.

As the damaged nuts from the long term survey plots were placed in the plantation immediately surrounding the plots, the total accumulation of damaged nuts could be compared with known damage for the area. Two survey plots and surrounding areas were checked and the damaged nuts found to represent only the previous nine months (Maravu Hill Plot 2) to 15 months (Maravu Hill Plot 1) known rat damage which suggested that the average accumulation represented only approximately a years' rat damage.

b) <u>Survey results</u>

Spot surveys were carried out at 43 sites on 11 islands in the Fiji group during 1969 - 1972 (Table 3.10).

Damage on short and tall palms showed the same trend that was observed in the long term survey plots; short palms incurred significantly more damage than tall ($t = 3.2$, $p > 0.01$). The Bua area of Vanua Levu (small stands of old palms), Lau, Lomaiviti and Kadavu Islands appeared to suffer very little damage, assuming the figures in Table 3.10 represented approximately one years' damage.

Surveys A and B (Table 3.10) were carried out during 1970-1972 and indicated an average yearly loss of 4.7 ± 0.43 nuts/palm/year. Long term surveys in the same region, but at different sites, established an average yearly damage level of 4.5 ± 0.41 nuts/palm/year; a difference of only 4.3 percent which suggests that a large scale spot survey is a reasonable method of assessing damage, bearing in mind the limitations discussed above.

Table 3.10 A SUMMARY OF SPOT DAMAGE SURVEYS 1969-1972

	Islands surveyed	Number of sites	Number of palms	Rat damaged fresh	Rat damaged old	Total damaged	Number damaged per palm	Notes
A	Vanua Levu and Taveuni	9	759	691	5001	5692	7.5	Short palms under 10 metres
B	Vanua Levu and Taveuni	10	635	129	797	926	1.5	Tall palms over 15 metres
C	Vanua Levu, Bua area	6	203	17	35	52	0.34	Tall palms over 15 metres
D	Matukụ, Moala, Lakeba, Yacata Vanuabalavu Cicia, Koro	10	402	169	569	738	1.8	Lau, Lomaiviti Islands, mostly over 15 metres tall
E	Kadavu	8	1132	6	266	272	0.24	Old palms, mostly over 15 metres tall

3.4 THE EFFECT OF ARTIFICIAL RAT DAMAGE ON COCONUT YIELDS

3.4 BACKGROUND

Earlier surveys of rat damage (Taylor, 1930; Paine, 1934; Smith, 1967; Smith, 1969), have given little consideration to the relationship between the number of nuts attacked and copra yield for it has generally been assumed that the relationship between the damage symptom (green holed nuts) and yield is direct. This assumption is questionable because it does not allow for the possible physiological impact that early nut removal could have either on the development of remaining fruit, or on subsequent flowering or fruit setting (Williams, 1971). The coconut palm normally produces more female flowers than develop to maturity and in the first few months some fruit are shed in a natural thinning process which is thought to keep the crop within the resource limits of the palm (Menon and Pandalan, 1957). Many factors such as nutrition, climate and insect attack affect this process.

Compensation for insect attack on the foliage of grain crops has been recorded by White (1946) and Davidson (1965). They simulated grasshopper injury and found that the stage of wheat when attacked, and type of injury governed the reduction in yield. Attack early and late in the growth cycle caused the greatest loss (13-28%) while during the stage of maximum growth loss was minimal (4-10%). In contrast rat attack on the foliage of young sweetcorn was found to have less effect on final yield than the initial loss of plants had suggested (Judenko, 1967). The remaining plants produced more and larger cobs.

Vanderplank (1959) and McKinlay (1965), working on the coconut palm, both demonstrated that there is a complex relationship between yield (i.e. harvestable nuts) and damage, the latter inflicted by the Coreid bug (Pseudotheraptus wayi) in the first three months of nut development. McKinlay (1965) found that reduction of this damage produced only a slight and transient increase in yield. From this result he concluded that the palm, by variations in physiological shedding or in the number of female flowers produced, adjusts its crop production to currently available resources.

In view of the clearly complex relationships between the level of pest attack, Williams (1971) postulated that rat induced nutfall, which occurs at a later stage of development than the insect attack discussed above, could affect the palm in three ways:-

a) Premature removal of nuts by rats could result in an increase in flower production.

b) Premature removal of nuts might affect nut setting rate.

c) If there is a reduction in the total number of nuts on the palm the remaining fruit could produce more kernel.

Any of these possibilities could result in smaller yield reductions than simple counts of immature damaged coconuts would at first suggest, so a trial was established to determine the relative importance of each. This was achieved by causing artificially, several levels of rat damage, this approach being necessary because the level of naturally occurring rat damage was too variable, the major factor being a marked concentration of rat attack on a limited number of palms. Since the basis of this selection was not known when the trial was started in 1970, yield from the type of palm favoured, in the absence of rat attack, could not be determined. Artificial simulation of damage is a recognised method of estimating the relationships between pest damage and crop loss (Judenko, 1965). It has been used with plants as diverse as beet (Jones et al, 1955) and pine trees (Austara, 1970).

3.4B EXPERIMENTAL METHODS

The trial was established in October 1970 on Maravu Estate, Vanua Levu and continued for two years (Figure 3.12). All palms in the areas selected were 14-18 m high, aged approximately 40 years and situated on a coastal strip of nigrescent soils. (Twyford and Wright, 1965). Foliar analysis in the study area revealed a general nitrogen deficiency which normally results in a low female flower production (Fremond et al., 1966).

Preliminary individual yield recording of most palms in the 3.3 hectare area was carried out. All bunches over approximately three months of age (mean nut length of 11 cm) were observed from the ground using binoculars, and the numbers of nuts recorded. As such a count approximates to a year's production this provided a measure of palm yield variation, enabling the optimum number of palms per treatment to be determined. Five groups of 40 palms each were assigned within the range 30-70 nuts per palm, each group having a mean of 45 $\pm$ 1.4 nuts per palm. In view of the S.E. 40 palm replicates per group were considered sufficient, particularly as all replicates of all groups were distributed at random throughout the 3.3. hectares.

Rat damage observed on a total of 910 palms at 10 sites over a 12 month period was used as a basis for establishing four levels of simulated rat damage. It was found that only

FIGURE 3.12

GENERAL VIEW OF THE ARTIFICIAL RAT DAMAGE TRIAL AT MARAVU ESTATE,

VANUA LEVU

Note the climber on his way to the palm crown to carry out recording

three percent of the palms lost more than 24 nuts per year and that the mean loss was 5.4 nuts per palm. Thus, four damage rates of D6, D12,D18 and D24 (D = damage rate) nuts per palm were chosen, the aim being to span the full range of damage encountered in the field.

Rat damage was simulated by punching a hole in the green nut with a 2 cm diameter steel cork borer, a satisfactory method for nuts up to about eight months of age after which the developing husk becomes too hard to penetrate. This form of damage caused all coconuts to fall within eight days. As rats favoured coconuts at a particular stage of development (Section 3.2., Table 3.1 and Figure 3.4), simulated damage levels were distributed between nuts of various ages so as to reflect this. Accordingly, 30 percent of the artificial damage was assigned to bunch five, 61 percent to bunch seven and 7 percent to bunch nine. Husk hardness prevented the damaging of nuts from bunches older than number nine, i.e. older than eight months. The annual distribution of the four simulated damage levels was calculated on a monthly basis (Table 3.11). Bunch number one in the system used was always the youngest visible and also the highest in the palm crown. Bunches five, seven and nine are at successively lower levels and will of course, become the sixth, eighth and tenth bunches respectively as soon as a new bunch unfolds. This system of bunch numbering from the youngest towards the oldest each month ensured that simulated damage was confined to the naturally favoured size classes.

All yield recording and induction of damage was done monthly by climbing the palm. New bunches were numbered, initially by attaching a tag, but later by etching a number on the stem of the frond subtending the bunch. Data recorded for each palm

Table 3.11 COCONUT DAMAGE RATES AND THE DISTRIBUTION OF DAMAGE ACCORDING TO BUNCH AND MONTH

Six nuts per palm per year

	Month 1	2	3	4	5	6	7	8	9	10	11	12
Bunch 5				1								1
Bunch 7		1				1			1		1	
Bunch 9												

Twelve nuts per palm per year

	Month 1	2	3	4	5	6	7	8	9	10	11	12
Bunch 5		1				1*				1	1	
Bunch 7	1		1	1	1		1	1*	1		1	
Bunch 9												1

* One nut removed from first 20 palms only

Eighteen nuts per palm per year

	Month 1	2	3	4	5	6	7	8	9	10	11	12
Bunch 5	1			1			1			1		1
Bunch 7	1	1	1	1	1	1	1	1	1	1	1	1
Bunch 9											1	

Twenty four nuts per palm per year

	Month 1	2	3	4	5	6	7	8	9	10	11	12
Bunch 5	1		1		1		1	1	1		1	
Bunch 7	1	2	1	1	1	2	1	1	1	2	1	1
Bunch 9				1							1	

included:

i) The number of female flowers or flower scars on bunches that had unfurled since the previous recording.

ii) The number of nuts set on the fifth bunch provided it had not been recorded previously.

iii) The number of harvestable nuts produced in the month and the weight of kernel from these.

All maturing nuts were colour coded on the palm to ensure that any that fell to the ground between recording periods could be assigned to the correct palm.

To prevent natural rat damage in the trial area, which was chosen partly because of the low damage level, poison was laid on several occasions during the two years of recording.

3.4C RESULTS

I) Effect of Simulated Rat Damage on Female Flower Production

An increase in the number of female flowers was considered the most likely response in view of earlier work (Vanderplank, 1959; McKinlay, 1965; Smith, 1969). Since damage in the present trial had a definite starting point, any increase in the number of female flowers produced could not be expected for at least 11 months as this is the average time lapse from formation of the female flower primordia to opening of the inflorescence (Fremond et al., 1966). Simulation of damage was started in November 1970 so data for the period November 1971 to OCtober 1972 was used to investigate the effect of damage on female flower production. The monthly records of flower production for each palm in all treatments were totalled and an analysis of covariance carried out on these data and equivalent data for the period October 1970 to August 1971 as this latter period was considered free of treatment effects.

Covariance analysis proved necessary since despite palm selection and spacial randomisation of treatments, there were clearly non-experimental differences in production.

Analysis of variance on the adjusted means indicated a significant difference between treatments ($F = 2.5$, $p > 0.05$, Figure 3.13), but despite covariance analysis the relationship between the four treatments, and the non-treated palms, was not linear. The lack of a linear relationship suggested a threshold response to damage level so a comparison of female flower production for treatments D0 and D6 (mean number of flowers 198.7 ± 15.3) versus D12, D18 and D24 (mean number of flowers = 224.2 ± 15.2) was carried out. It indicated a significant difference between the two groups.($F = 5.5$, $p => 0.025$).

The average flower production increase in response to treatments D12, D18 and D24 was 30, 15, and 31 per palm per year respectively. This increase would be subject to the same natural reduction, from such causes as pollination failure and premature nutfall, as flowers produced under normal conditions.

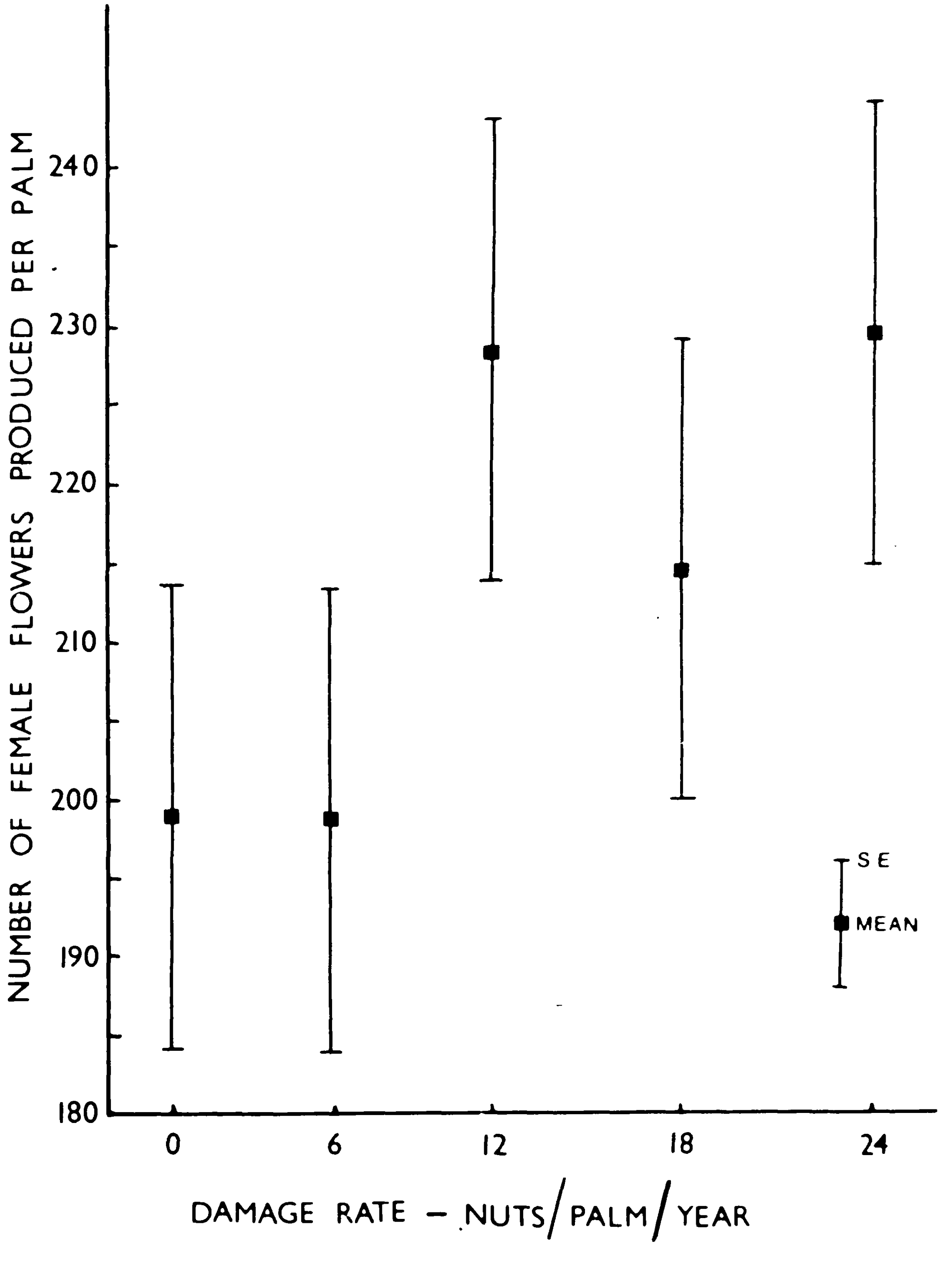
II) Effect of Simulated Rat Damage on Setting Rate.

A second possible response to rat induced nutfall is an increase in the percentage of flowers set and retained beyond the third month, because under normal conditions approximately 66 percent of flowers fail to be pollinated or the resulting nutlets are prematurely shed.

This aspect was investigated using the number of nuts retained by the third month on inflorescences that opened between August 1971 and July 1972. Covariance analysis was used to adjust the means of nuts set for variations in the number of flowers produced, that is,to separate the possible

FIGURE 3.13

THE EFFECT OF FOUR LEVELS OF ARTIFICIAL DAMAGE ON THE NUMBER OF FEMALE FLOWERS PRODUCED PER PALM PER YEAR



NUMBER OF FEMALE FLOWERS PRODUCED PER PALM
240
230
220
210
200
190
180
0
6
12
18
24
DAMAGE RATE – NUTS/PALM/YEAR
SE
MEAN

increase in flowers set from the known increases in the number of female flowers produced. Analysis of variance on the adjusted means showed no significant difference between groups indicating no change in the percentage of nuts set and retained beyond the third month in the presence of those simulated levels of rat damage.

The actual setting rates for the five treatments averaged 33.2 $\pm$ 1.8 percent although there was some variation between treatments (Table 3.12). If this average rate is applied to the known increases in female flowers (discussed above), the increases in nuts per palm per year for treatments D12, D18 and D24 become 11.1, 5.0 and 10.1 respectively. These increases represent 92.0, 28.0 and 42.0 percent of the number of nuts removed per year.

Premature nutfall for reasons other than rat or insect attack (i.e. possible physiological stress) is not confined to the first two to three months of nut development, but extends to the eighth or ninth month. The number of such larger nuts lost is relatively small (Table 3.13) but nevertheless this form of nutfall may interact with rat induced fall; the former decreasing as the latter increases, thus providing a compensatory mechanism.

Data directly supporting this hypothesis was not accumulated during the trial but the lack of any marked decrease in the number of harvestable nuts produced by the highest damage levels indicated some form of compensation must operate. The known increases in female flowers could not have compensated for the simulated damage since only in the 24th month would the increases have begun to be evident in the number of nuts harvested. This is because the time lapse from flower initiation at the apical primordia to nut maturity is at least 23 months. However

Table 3.12. NUT SETTING RATE DURING DAMAGE SIMULATION TRIAL

(November 1971 - November 1972)

Treatment D	Number of female flowers produced	Number of nuts set by 4th month	Percentage of nuts set
0	8153	2671	32.8
6	7606	2917	38.4
12	9404	2834	37.3
18	9083	2999	33.0
24	9576	3118	32.6
Totals	43,822	14,539	
	Mean number set		33.2 ∓ 1.8

Table 3.13. FALL OF IMMATURE COCONUTS NOT DUE TO RAT DAMAGE

(all nuts over three months old, length $>$ 10 cm)

Plot site	Number of palms	Nutfall per palm per year	
		1970	1971
Maravu Hill 1	100	7.4	3.5
Hill 2	100	3.6	2.5
Coastal 1	50	1.8	2.1
Coastal 2	100	2.3	-
Vunilagi 1	50	1.6	2.2
Vunilagi 2	50	2.9	2.5
Nabaka	40	-	1.6

another form of compensation such as that proposed above is clearly coming into operation within 18 months of damage being started, for although there is a significant drop in harvestable coconuts produced by the D24 group ($p => 0.05$) in the second six month period, such a decrease is not apparent in the third and fourth month periods (Table 3.14).

Table 3.14 MEAN NUMBERS OF NUTS PRODUCED PER PALM FOR SIX MONTHLY PERIODS DURING A 24 MONTH DAMAGE SIMULATION TRIAL

Simulated Damage rate per palm per year (treatments)	Number of Harvestable Nuts per Palm			
	Nov. 1970- April 1971	May 1971- Oct. 1971	Nov. 1971- April 1972	May 1972- Oct. 1972
0	24.4 ± 1.4	23.7 ± 2.3	28.0 ± 1.4	26.7 ± 1.3
6	25.9 ± 1.2	25.5 ± 1.6	30.9 ± 1.6	32.3 ± 1.8
12	21.7 ± 1.3	23.7 ± 1.7	28.8 ± 1.9	27.6 ± 1.7
18	23.5 ± 1.3	20.4 ± 1.9	29.2 ± 1.8	25.7 ± 2.2
24	23.3 ± 1.2	19.2 ± 1.2	26.6 ± 2.0	27.4 ± 1.7

$\pm$ = S.E. of mean.

III) Effect of Simulated Damage on Yield of Kernel per Nut.

A third possible response to rat damage is an increase in the yield of flesh per nut following a reduction in the number of nuts on a palm. Such a response would be most likely to occur if the number of nuts were reduced over a relatively short period, since there would be insufficient time for other compensatory responses to become effective. As the first year of damage simulation paralleled such a situation the average yield of flesh per nut for the five treatments in the period May to October 1971 (i.e. the sixth to twelfth month of the trial was compared (Table 3.15). Analysis of variance indicated no difference between groups ($F = 1.3$).

Table 3.15 MEAN WEIGHT OF FLESH PRODUCED PER NUT DURING THE SIXTH TO TWELFTH MONTHS OF A 24 MONTH DAMAGE SIMULATION TRIAL

Simulated damage rate per palm per year (treatments)	Average yield per coconut (grams $\pm$ S.E.)
0	312 $\pm$ 9.5
6	326 $\pm$ 8.9
12	323 $\pm$ 7.5
18	311 $\pm$ 7.5
24	336 $\pm$ 9.5

In retrospect the lack of an increase in yield per nut, within the limits of the trial, was not surprising for despite a significant difference in the number of harvestable coconuts produced by the D0 and D24 treatments during the period investigated the actual difference was not great (Table 4.14) and was not apparent during later periods. While there was no marked or long term reduction in the total number of nuts carried by the palms there would be no stimulus to increase the flesh content of each coconut.

3.4D DISCUSSION

The increase in the number of female flowers is the most obvious palm response to rat induced nutfall revealed by this trial. However the apparent ability of palms to compensate for rat damage relatively quickly, i.e. before the increase in female flowers can influence production, is of major importance even though the proposed mode of compensation does not appear able to account for all that occurs. The mechanisms controlling the female flower response can only be postulated for although a considerable amount is known about the control of fruiting in temperate tree crops, such as pears and apples, little is known about coconuts. Nevertheless it is probable that factors controlling flowering and premature nutfall in coconuts are similar to those of temperate tree crops even though coconut flower and fruit production is a continuous process.

In apples, giberellins produced by apical growing regions and the developing apple seeds are considered the most important hormones associated with the formation of flowers (Luckwill, 1970) It is thought that the presence of high levels of giberllins, particularly those produced by the developing seed, may constitute the factor that causes an apple bud to remain vegetative and the tree spurred to crop biennially. In short, giberellins produced by one crop of fruit govern the size of the subsequent crop. Hormones produced by the developing coconut would well form the basis of a mechanism for regulating flower production even though their formation is continuous and there are clearly many more flowers produced than the average palm can carry through to maturity. However excess flower production and fruit set is a common feature of tree crops and the shedding of immature fruit, which in apples is governed basically by the availability of essential metabolites (Abbot, 1960), adjusts the crop to the carrying capacity of the tree.

Although little is known about the hormonal control of coconut flowering two authors have suggested that there may be an interaction between flower production and pest induced premature nutfall. Vanderplank (1959) and McKinlay (1965) both thought that immature nutfall caused by P. wayi could influence the production of female flowers. In a trial aimed at investigating P. wayi damage on overall coconut production, McKinlay (1965) sprayed a series of plots to eliminate the insect while an adjacent series were not controlled. McKinlay's trial was thus similar to that described in this thesis with the basic difference that instead of damage being inflicted artifically it was reduced. In the first year of the trial there were more undamaged immature nuts on the insect controlled plots than the uncontrolled while in the second year this situation was reversed. Such a response would be expected if palms adjust the number of female flowers in response to the level of pest induced nutfall. In the first year all the spathes that had formed while under insect attack would open and would probably be be carrying an excess of female flowers. With insect attack at a low level, premature nutfall could be expected to increase once palms were carrying a maximum crop. During the second year the spathes that opened would have developed after insect attack had been controlled and consequently bore fewer flowers. Thus the level of undamaged nutfall could be expected to drop.

Vanderplank (1959) noted the same response at an earlier stage. He reported that the average number of female flowers per inflorescence fell from 20.0 to 7.5 following control of P. wayi and in addition the number of inflorescences decreased from 17-18 per year to 15-16. Both these responses suggest that palms boost floral production to compensate for pest induced nutfall.

Smith (1969), working on rat damage in the Gilbert and Ellice Islands, also provided data suggesting a palm response to premature coconut loss. During a rat poison trial (nine plots, 1450 palms) records of rat induced and other nutfall were kept for a week prior to poisoning, and a week four weeks after start of treatment. Nutfall pre and post treatment was as follows:-

Nutfall	Pre treatment	Post treatment	Percentage change
Rat induced	707	30	44
Other reasons	392	528	35

There was clearly a very marked drop in the number of rat damaged nuts after treatment but the 35 percent increase in other forms of nutfall is the point of particular note. It suggests that because of the reduction in rat damage, palms were retaining more nuts than they could support and hence 'natural shedding' had to increase. This in turn indicates that the palms must have been responding to rat induced nutfall by increasing female flower production.

Long term monitoring of rat damage on individual palms also provided data that suggested a compensatory response (Table 3.8). It is concluded that the palms selected are compensating by either an increase in female flower production or the postulated mechanism whereby a decrease in other forms of advanced immature nutfall reduces the effect of rat damage. This latter mechanism is clearly not fully understood.

The experimental results presented, in conjunction with the work reviewed, clearly indicate that the coconut palm can compensate in one or more ways for rat induced nutfall. However it seems that a palm may not compensate for all rat damge, because a moderate percentage of the ultimate material content of a nut has already been incorporated at the stage of development favoured by rats.

An investigation of the dry matter content of such nuts indicated that they contained 23.9 - 29.2 percent (95% limits, N = 59) of the dry matter content of mature coconuts suggesting that only approximately 75 percent of the material resources that would have been expended on the coconuts lost could be deployed in replacements. Thus the upper limit of compensation is possibly 70-75 percent of the number damaged. Actual palm compensation will depend to a considerable degree on the physical environment and genetic characters of each palm; with results from the present trial indicating that it is probably between 28 and 75 percent of the number lost.

In view of the number of unknown factors associated with palm compensation for rat damage an average response that replaces 50 percent of the number of nuts damaged would seem to be a realistic level for most plantations. This means that the counts of immature damaged coconuts that have characterised surveys must be halved before they can represent a loss of yield.

3.5 THE IMPACT OF RAT DAMAGE ON COCONUT PRODUCTION IN FIJI

The comparison of yield (number of harvested nuts) from palms incurring high and low levels of damage indicated that there was no difference between the two groups (Tables 3.7 and 3.8). In addition the trial to investigate the effects of known levels of simulated rat damage on palm productivity established that there was an increase in female flower production (Figure 3.13) and no apparent decrease in the number of harvestable coconuts produced even before the flower increase could influence yields (Table 3.14); responses to the loss of developing coconuts that were conservatively estimated to compensate for 50 percent of the nuts attacked. These two lines of investigation, the first a field observation the second an experimental result, lead to the conclusion that there is certainly not a direct relationship between the damage symptom and actual loss of production. The palm's ability to compensate for nuts lost early in the development cycle means that counts of rat damaged coconuts, as carried out during both surveys, cannot be directly equated to a loss of mature nuts but need to be reduced by about 50 percent before they indicate actual production loss. To illustrate this point the overall level of damage on all plots over the three years can be recalculated to express actual loss:-

		Nuts/palm/year	Nuts/hectare/year
1970	Surveyed damage	5.4	793
	Actual loss	2.7	396
1971	Surveyed damage	3.9	544
	Actual loss	2.0	272
1972	Surveyed damage	2.5	452
	Actual loss	1.3	226

This illustrates that the average loss was relatively low during the survey period and it is of note that even on individual survey sites such as Maravu Hill Plot 2 the loss did not exceed four nuts/palm/year. At these low levels economic control by poisoning or banding the palm trunk with an aluminium strip is very dependent on the price of copra and overall plantation efficiency.

Control methods and economics are discussed in Chapter 4.

THE EFFICIENCY AND ECONOMICS OF DAMAGE REDUCTION METHODS

CHAPTER 4

4.1 INTRODUCTION AND REVIEW

Possible methods of reducing rat damage in Fiji have been considered since 1925 when Turbet (1925) suggested a widespread rat destruction programme using poisons, trapping and galvanised palm trunk collars. In 1932, Taylor also recommended the use of poisons such as red squill, and discussed the possibility of employing various biological methods, including viruses. Taylor rejected the use of metal bands on the grounds that in his experience of them, in Tahiti, they required too much effort to prevent coconut fronds or other trees from bridging the bands.

Lassalle-Sere (1955) summarised the results of banding trials carried out in Tahiti in 1951. In sixteen plots of 50 palms each, four were banded with the remainder acting as controls. Twelve months data clearly showed that banding reduced damage in areas of tall mature palms surrounded by little undergrowth. Lassalle-Sere assumed that the reduction in damage produced a corresponding increase in yield but the data was later shown by Williams (1971) not to support this assumption. Between 1955 and the mid 1960's a large scale banding programme was carried out in Tahiti, financed by a levy on copra (Millaud, 1966). However, banding was discontinued in the late 1960's as it had not been shown that it resulted in an economic increase in copra yield (Millaud, personal communication, 1972).

Yelf (1966) advocated banding in Fiji using aluminium alloy 30 cm wide. However he established neither the prevailing level of rat damage nor its effect on yields and hence economics, which was probably why only limited areas of palms were banded in the following two to three years.

In Jamaica and the Gilbert and Ellice Islands (R.W. Smith, 1967; and F.J. Smith, 1969) it was demonstrated that cereal meal based baits, incorporating paraffin wax as a water-proofing agent and the poison warfarin (3-1-phenyl-2-acetylethyl)-4-hydroxycoumarin), would reduce rat damage in coconut plantations. Smith (1967) treated one area of 225 palms in Jamaica, where damage was severe, and seven weeks after the first treatment found that damage was reduced from an equivalent of 32 to only two nuts per palm per year. However no data were provided to suggest that any economic increase in yield resulted and banding was rejected on account of the expense and the difficulty of keeping plantations free of hanging fronds, creepers or other interplanted tree crops which serve as bridges across the bands.

In the Gilbert and Ellice Islands Smith (1969) attached warfarin baits to every fifth palm trunk six feet from the ground and in one large scale trial (1450 palms in nine plots) reduced damage four weeks after poison applications from the equivalent of 25 to one nut per palm per year. In other trials in the Gilbert and Ellice Islands zinc phosphide baits were used as well as warfarin but Smith, like other workers, produced no data to suggest any resultant increase in coconut yield. Banding was found to be inefficient under atoll conditions, primarily because of salt spray induced corrosion of the aluminium band. Dense, irregular stands of palms also meant that many bands were bridged by hanging fronds or other vegetation (Smith, 1969).

Banding is theoretically the best method of reducing rat damage in coconut plantations because it has little impact on the rat population. Rats that normally forage in the palm crowns should be excluded but there is no data to suggest that this would cause the population to disperse or attack other crops. In addition banding, in contrast to poisoning, does not unleash the considerable reproductive potential of Rattus populations. In view of these advantages, and the effort made by Yelf (1966) to locate a suitable banding material, it was considered desirable to investigate the efficiency and economics of trunk banding in addition to confirming the known effectiveness of poisoning under Fiji conditions.

4.2 METHODS AND RESULTS

4.2A BANDING

I. Materials and Methods

Yelf (1966) made considerable efforts to locate a low cost, durable banding material and 0.15 mm thick aluminium alloy with a projected life of 20 years was chosen. Black sheet plastic, 0.25 mm thick was also tested but was not considered suitable for widespread use as it became brittle after five to seven years exposure to sunlight and was thus easily damaged by wind or falling fronds. After cage trials with Rattus rattus, Yelf established that an aluminium band 25 cm wide prevented rats from climbing palm trunks. However, to allow for non-vertical trunks he recommended 30 cm bands fixed by aluminium nails 4.5-5.0 m from the ground. This height was arbitrary but it placed the band above the thicker lower trunk (saving material) and avoided risk of damage by cattle or bridging by creepers. As considerable stocks of the 30 cm wide banding material, used by Yelf, were on hand in 1970 this material was used for all banding trials.

Three trials were established in 1970 to assess the efficiency of banding under general plantation conditions. Two were located on stands of younger palms (nine to ten metres high) as it was apparent at an early stage of the damage assessment programme that short palms incurred more damage than tall ones (Section 3.3B).

Trials on short palms were carried out on the island of Taveuni with one site at the northern end (Tuvamaca plantation, Figure 4.1) and another near the southern tip (Wainiyaku plantation, Figure 4.2). At the former site palms were 9-10 m high while at the latter they were 3.5-4.5 m. In addition, a trial on tall palms (over 15 m) was established on Vunilagi Estate, Vanua Levu, an area banded by the estate in 1968. On each of the Taveuni sites a uniform stand of 1000-1200 palms was divided into two and approximately half the area banded. Bands, depending on palm height, were placed 3.0-4.5 m from the ground. Six 20 palm plots were located within each of the banded and unbanded areas, all plots within each area being separated by at least one row of palms, while there were six to eight rows between the two areas. Damage and production were recorded at Tuvamaca and Vunilagi but only damage was recorded at Wainiyaku.

All recording was done at monthly intervals. Tuvamaca and Wainiyaku plots were banded in January 1970, but recording was not begun until December 1970. The 11 month delay was to allow production from the banded palms to recover from the effects of previous rat damage (assuming there was an effect, Section 3.4), for the time lapse from flowering to maturity was approximately 12 months (Figure 1.7).

II. Results

At Tuvamaca in 1971 (Table 4.1) there was significantly less damage on the banded plots ($F = 7.4$; $p > 0.025$). Nevertheless, the higher level of damage on the unbanded plots, which had probably been current for several years, did not result in significantly less production in either 1971 ($F = 1.9$) or 1972 ($F = 3.2$). This was not an entirely unexpected result in view of the known responses to rat induced nutfall, which enables palms to compensate for at least 50 percent of rat damage (Section 3.4).

FIGURE 4.1

GENERAL VIEW OF THE TUVAMACA PLANTATION AT THE BOUNDARY BETWEEN THE BANDED AND UNBANDED AREAS

Note the density of the palms and the location of the bands

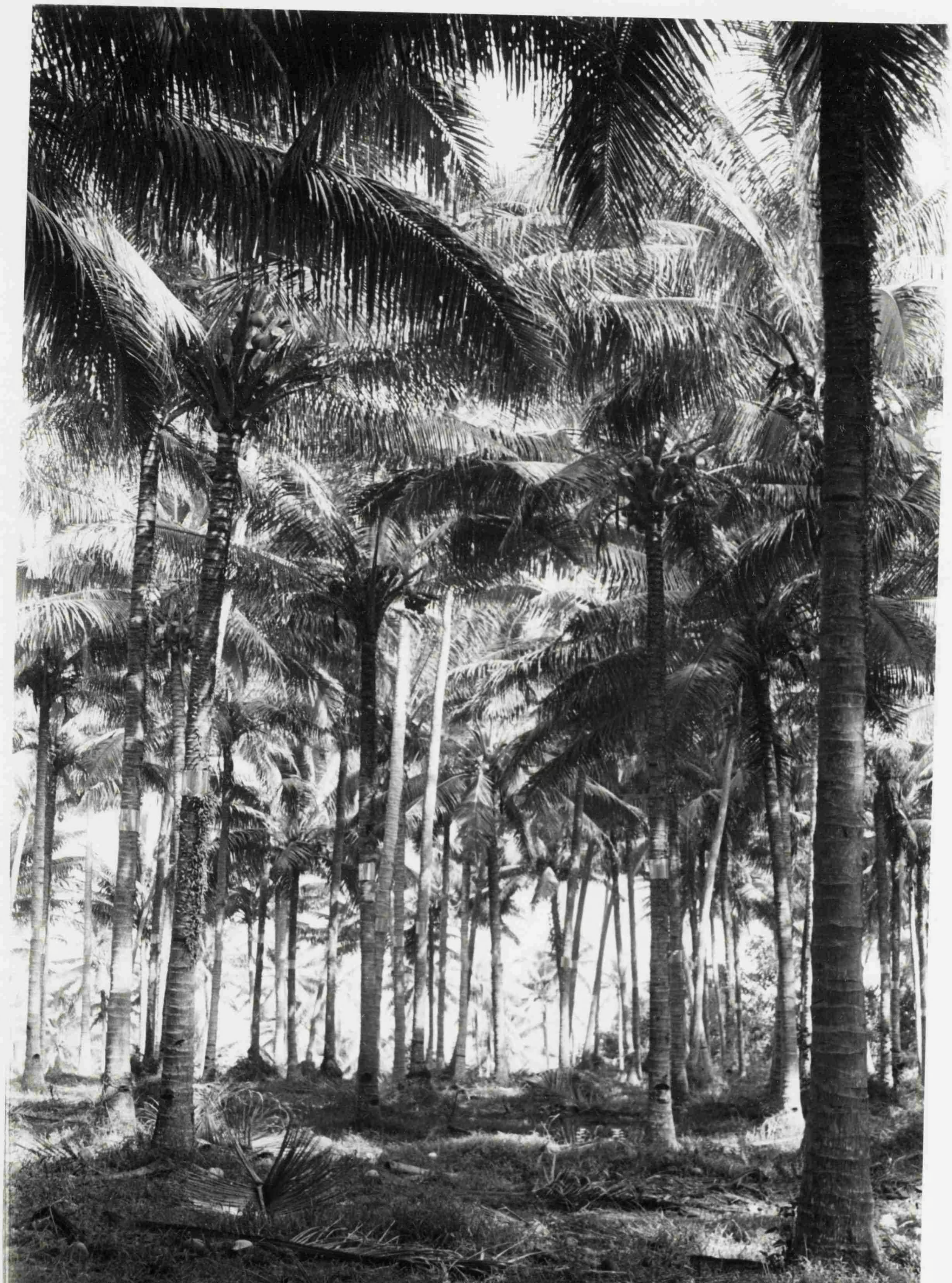


FIGURE 4.2

GENERAL VIEW OF THE WAINIYAKU PLANTATION AT THE BOUNDARY BETWEEN THE BANDED AND UNBANDED AREAS

Table 4.1 SUMMARY OF BANDING TRIAL AT TUVAMACA ESTATE, TAVEUNI

A.

1970 - 1971 (12.6 months)						
Plot number	Number of nuts rat damaged		Number of nuts harvested		Wet copra weight (kilos)	
	Banded	Unbanded	Banded	Unbanded	Banded	Unbanded
1	82	105	666	771	212	250
2	119	123	760	530	247	233
3	85	130	919	924	290	305
4	83	108	1045	703	292	246
5	104	143	894	725	285	241
6	107	112	997	611	319	196
Mean per plot	96.7	120.2	880.0	710.0	274.0	245.0
S.E. ±	6.3	6.0	58.6	54.1	15.6	14.4
Mean difference between banded and unbanded plots	-23.5		+170		+29.0	
Banding efficiency* (percentage)	19.5					

B.

1972 (9.4 months)						
Plot number	Number of nuts rat damaged		Number of nuts harvested		Wet copra weight (kilos)	
	Banded	Unbanded	Banded	Unbanded	Banded	Unbanded
1	41	66	506	690	179	234
2	151	65	635	486	208	162
3	76	85	693	580	225	202
4	84	42	817	550	250	204
5	111	91	827	625	277	224
6	114	86	737	503	253	165
Mean per plot	96.2	72.5	703.0	572.0	232.0	199.0
S.E. ±	15.4	7.5	49.2	31.3	32.2	27.1
Mean difference in damage between banded and unbanded plots.	+23.7		+131		+33	
Banding efficiency* (percentage)	0					

* see text for explanation of this term.

Despite such factors, limited replication could have obscured a difference in yield between plots, therefore the standing crop (i.e. coconuts on the palm over four months old) was counted in March 1972. This method of yield assessment also showed that there was no significant difference between the number of coconuts produced by banded and unbanded plots (mean per plot 49.2 and 47.7 respectively, F = 1.8, n = 240 palms)

Banding significantly reduced damage at Wainiyaku in both years (Table 4.2A) and completely eliminated damage at Vunilagi (Table 4.2B although the damage was clearly very low in the area.

Banding efficiency (i.e. the reduction in damage produced by the presence of the band) can be illustrated by expressing the difference in damage between banded and unbanded plots as a percentage. For example, where bands prevent all damage the percentage efficiency would be 100. In the current trials efficiency ranged from zero to 100 percent with maximum efficiency being reached only on tall palms (Tables 4.1 and 4.2 .

Bands did not appreciably reduce damage on shorter palms and possible reasons for this were investigated. Senile fronds hanging parallel to the trunk, just before detachment, on palms with a trunk height of less than 12 m, usually bridged the band (Figure 4.3). In addition, creepers and ferns growing on or climbing the palm trunk also caused bridging. Five monthly surveys of the Taveuni trials in 1972 showed that an average of 20 bands per site (480 banded palms at Tuvamaca, 340 at Wainiyaku) were bridged on the days surveyed. Such fronds provided easy access to palm crowns which if continguous enabled numerous trees to be reached. The low efficiency of bands at Tuvamaca was possibly a reflection of palm density which at 210 per hectare was considerably greater than the 110 per hectare at Wainiyaku. In the dense Tuvamaca plantation the fronds ofpalms overlapped, forming an almost complete canopy (Figure 4.1), which probably enabled rats to move freely from palm to palm once they had crossed a band. Such crown movement by R. rattus and R. exulans was observed during crown inspections at the Salt Lake survey site.

FIGURE 4.3

PALM FROND BRIDGING A BAND AT THE WAINIYAKU TRIAL PLOT

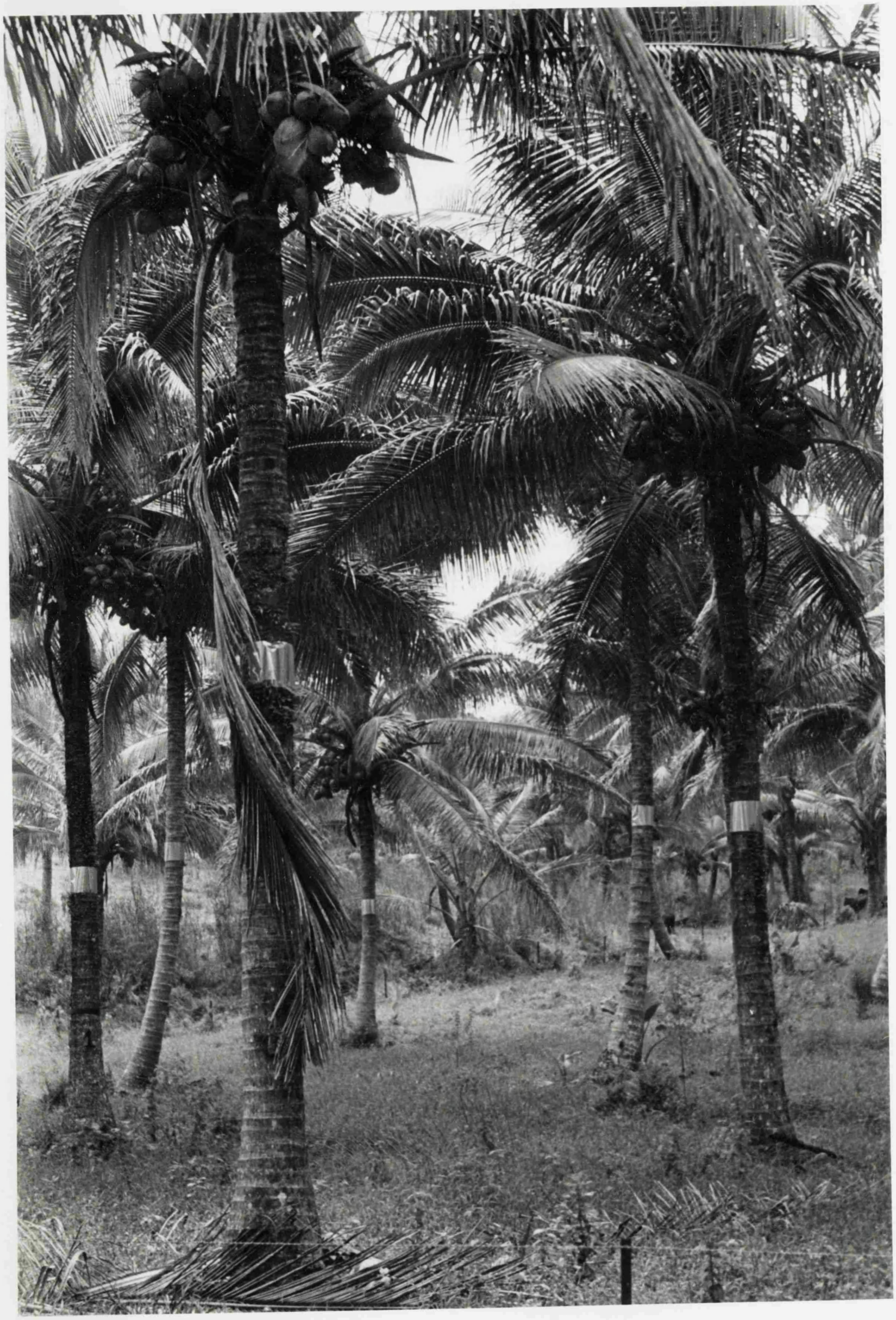


Table 4.2 BANDING EFFICIENCY TRIALS

A. Wainiyaku Estate, Taveuni

1971 (11.7 months)			1972 (9.3 months)		
Plot Number	Number of nuts rat damaged		Plot Number	Number of nuts rat damaged	
	Banded	Unbanded		Banded	Unbanded
1	37	127	1	46	146
2	85	50	2	13	106
3	30	106	3	20	98
4	34	114	4	25	85
5	42	168	5	36	176
6	48	173	6	65	150
Mean damage per plot	46.0 ± 8.2	123.0 ± 18.4		34.2 ± 7.8	126.8 ± 14.5
Mean difference in damaged between banded and unbanded plots	-77.0			-92.6	
Banding efficiency (percentage)*	63.0			73.0	

B. Vunilagi Estate, Vanua Levu

1972 (5.0 months)				
Plot Number	Number of nuts rat damaged		Number of nuts harvested	
	Banded	Unbanded	Banded	Unbanded
1	0	3	212	242
2	0	1	311	271
3	0	1	263	236
4	0	8	253	220
5	0	0	262	218
6	0	0	291	249
Mean damaged per plot	0	2.2	265 ± 13.8	239 ± 8.0
Mean difference in damage between banded and unbanded plots	-2.2		+26	
Banding efficiency* (percentage)*	100			

* see text for explanation of this term

In contrast, the incomplete canopy at Wainiyaku probably reduced inter-crown movement, confining rats to the palm actually climbed. R. rattus and R. exulans were trapped on both properties and as the level of damage on the unbanded plots was similar it suggests that the rat population levels did not differ greatly between the two areas.

It therefore appears that for bands to be effective palms must be tall enough for them to be placed below the reach of senile fronds but above creepers climbing from the ground. The trunk height therefore needs to exceed 11.0-12.0 m so that bands can be placed at least 3.0 m up the trunk without senile fronds measuring 6.0-8.0 m bridging them. Under these conditions damage should be prevented as long as bands remain in good condition.

The durability of aluminium bands that had been in place on 235 palms for seven years was investigated on Wainiyaku Estate in July 1971. Ten bands were missing (4.2 percent), possibly a result of faulty installation, but more probably as a result of corrosion around the area of band overlap which, because it tends to be on the underside of the trunk, is exposed to rain water draining from the palm crown.

Samples of corroded material were tested by the manufacturers (Astral Crane) in Australia. Traces of phosphates were found which could have been leached out of animal excreta (birds, lizards, etc.), decaying plant material (trunk lichens, ferns and fronds), soil, fertilisers, herbicides, or contained in salt spray from the ocean 3.5 km away. These phosphates combined with moisture trapped under the band were considered by the manufacturers to be the main cause of corrosion, the impact of corrosion on band life being closely related to the thickness of the aluminium alloy. In a high rainfall area (over 3100 mm/year), such as Wainiyaku, most bands showed signs of corrosion after seven years of exposure. While it is difficult to estimate accurately the effective life span of a 0.15 mm thick alloy band, corrosion caused by the factors discussed above must eventually affect most bands. Assuming corrosion increases exponentially the 4.2 percent loss in seven years suggests most bands would have fallen off after 20 years.

4.2B POISONING

Legislation governing the use of poisons in Fiji prevents the widespread use by unskilled personnel of acute poisons such as zinc phosphide. Trials, using various bait bases, were therefore limited to the anticoagulant warfarin during rat control studies in cocoa plantations (Chapter 5). Trial work was concentrated on use of the lowest priced commercial preparation (warfarin impregnated wheat set in wax) since it was difficult for the average farmer to prepare adequately baits of grated coconuts or similar material that proved consistently attractive to rats. In addition, very few centres in Fiji had supplies of paraffin wax for producing a waterproof bait.

As Smith (1967) and Smith (1969) carried out extensive poison trials in coconut plantations in Jamaica and the Gilbert and Ellice Islands it was considered unnecessary to do extensive trials in Fiji. However, a limited trail was carried out to confirm both their findings and those of work done in cocoa plantations in Fiji (Section 5.4). Since bait acceptance trials in cocoa showed that the commercial paraffin/wheat preparation produced good results under most field conditions it was used in the coconut trial. The site selected was on Maravu Estate, Vanua Levu (Hill Plot 2, Section 3.3 B) which had been a part of the long term damage survey area.

When the survey was completed in August 1972, 30 palms (in the 100 palm plot) with a history of regular rat damage were selected and 115 g baits tied to the trunks 2.75 m from the ground. Palms favoured by rats were used as bait points in an attempt to ensure maximum rat/bait contact and thus increase the effectiveness of poison applications. Since very few of the baits were attacked during the first five days after laying they were all transferred to the palm crowns as the trunks may have been an exposed feeding position. In the following 10 days 2.5 kg of bait were eaten and no damage to coconuts was recorded until 12 weeks later. This marked reduction was attributed to the poison, for in the years 1969 to 1972 damage on the plot rose noticeably in the last three to four months of each year. Poisoning thus clearly reversed this trend in 1972 (Figure 4.4).

This short term trial of limited scope, indicated that damage can virtually be eliminated for up to three months in a plot of one hectare. A practical problem may exist in the apparent need to place baits in the palm crowns, although it should be noted that in the Gilbert and Ellice Islands Smith (1969) obtained good results with baits placed on trunks, perhaps because of the absence of predators such as the Barn Owl (Tyto alba).

Provided there is no danger to domestic livestock and interference by crabs is limited, ground-placed baits should give good results even if bait consumption is increased by R. exulans, a species that causes less damage to coconuts than R. rattus, since it does not forage in the crowns of tall palms as frequently as the latter (Section 2.3C).

Since trials in cocoa (Chapter 5) suggested that as few as 16 bait points per hectare provided good control, a similar spacing would probably be satisfactory in coconuts. Thus three applications per year, at a rate of 3 kg per hectare per application would on the basis of cocoa trials, give satisfactory control.

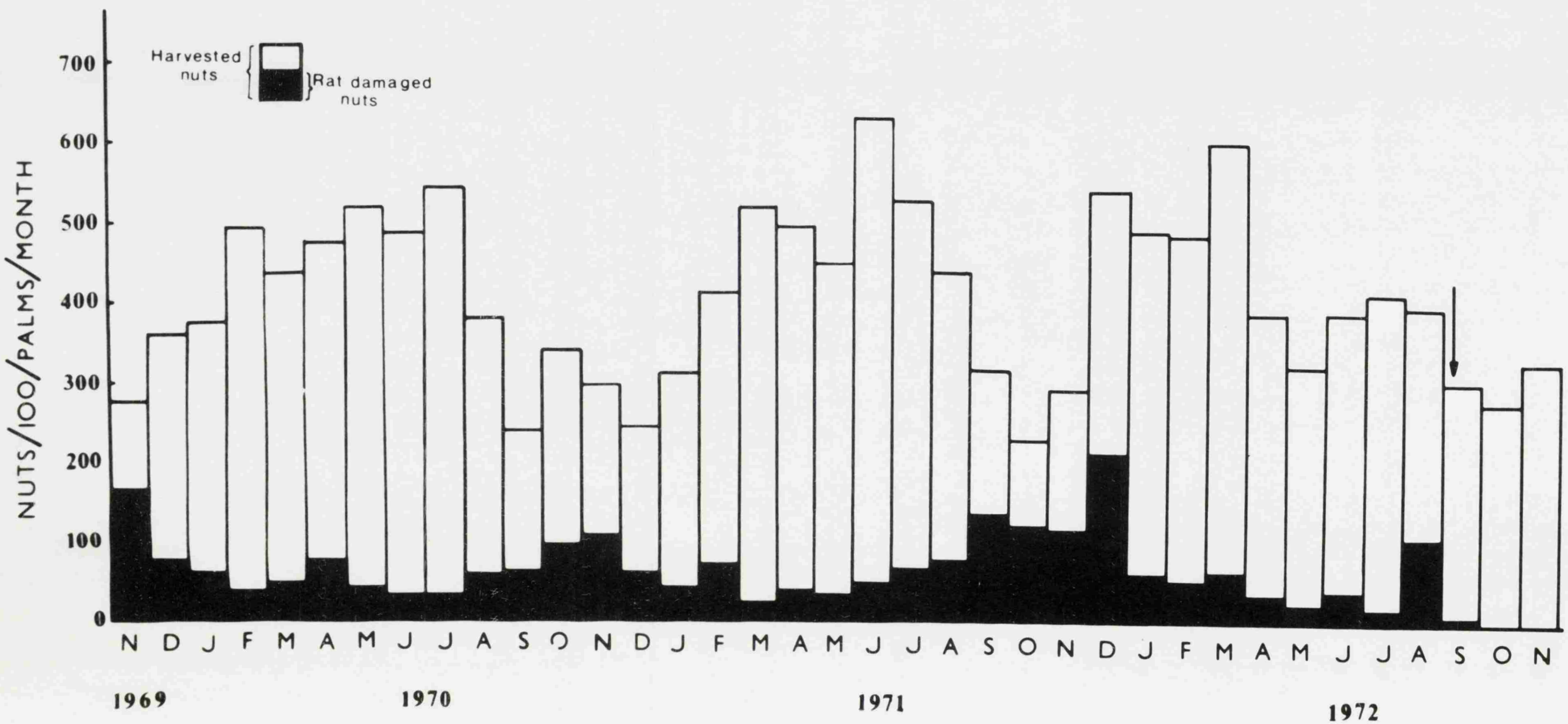
Smith (1967) recommended three to four 6 kg applications of an anticoagulant block per hectare per year for Jamaica plantations, but no allowance was made for waste or the drop in consumption that occurs when an area is poisoned over a number of years. (Section 5.4B).

FIGURE 4.4

THE EFFECT OF A SINGLE POISON TREATMENT ON THE LEVEL OF RAT DAMAGE

AT MARAVU HILL PLOT TWO

Arrow indicates date poison laid



NUTS/100/PALMS/MONTH
0
100
200
300
400
500
600
700
Harvested nuts
Rat damaged nuts
N D J F M A M J J A S O N D J F M A M J J A S O N D J F M A M J J A S O N
1969
1970
1971
1972

Smith (1969) recommended an application rate of 6 kg of an anticoagulant block per hectare but considered repeated applications could be governed by subsequent damage levels.

4.3 CONTROL COSTS IN COCONUTS

The 1969 to 1972 survey of rat damage in Fiji revealed levels ranging from zero to 9.2 nuts per palm per year, with mean damage per palm per year at all sites being 5.4 in 1970, 3.9 in 1971 and 2.5 in 1972 (Section 3.3B). However, a trial to investigate the effects of known levels of simulated rat damage, ranging from 0 to 24 nuts per palm per year, on palm productivity established that there was an increase in female flower production and no apparent decrease in the number of harvestable coconuts even before the flower increase could influence yield; responses to the loss of developing coconuts were conservatively estimated to compensate for 50 percent of the nuts attacked (Section 3.4). Thus the damage levels quoted above have to be reduced by approximately one half in order to represent an actual production loss (Section 3.5).

Table 4.3 presents the practicability of rat control methods in coconut plantations in Fiji. Since corrosion may cause a high loss over a longer period the installed life of aluminium bands has been set rather arbitrarily at 15 years. The installed cost of bands was derived from estate accounts in 1971 (Morris Hedstrom Ltd.). The capital cost of banding plus interest have therefore been spread over 15 years which, while producing alower cost than poisoning, has serious disadvantages. For example, it has been shown (Section 3.3B) that coconut losses vary considerably from year to year while the gross value of copra can range from 75 Fijian dollars per tonne (mid 1972) to 250 dollars per tonne (September 1973). These two

Table 4.3 CONTROL COSTS IN COCONUTS AT A SERIES OF VALUES PER TONNE

(Losses and costs per hectare per year)

Loss/palm year* (No. of coconuts)	$70/Tonne gross+ $24/Tonne net			$100/Tonne gross $54/Tonne net			$150/Tonne gross &104/Tonne net			&200/Tonne gross $154/Tonne net		
	Net value of loss per hectare	Control feasibility		Net value of loss per hectare	Control feasibility		Net value of loss per hectare	Control feasibility		Net value of loss per hectare	Control feasibility	
		Poison	bands		poison	bands		poison	bands		poison	bands
2	$1.50	X	X	$3.30	X	X	$6.40	X	X	$9.50		
4	$2.95	X	X	$6.50	X	X	$12.80	X	X	$18.85		
6	$4.45	X	X	$9.80	X		$19.20			$28.40		
8	$5.90	X	X	$13.10			$25.60			$37.90		
10	$7.40	X		$16.30			$32.00			$47.40		

* Real loss after allowing for 50 percent compensation (see text) + F$2.00 = approx £1.00

Notes

1) Cost of poisoning plus eight percent per annum for one year = $8.22 per hectare per year where:-
   poison = 50 cents per kilo (nine kilos per hectare per year)
   labour = 42 cents per hour and 7.5 hours per hectare per year
2) Cost of banding plus eight percent per annum for 15 years = $5.26 per hectare per year where bands costed at 30 cents each with a life of 15 years and 90 percent effective.
3) Palm density per hectare = 160
4) Production calculated at 5,200 nuts per tonne and a yield of approx. one tonne per hectare per year (eight cwt per acre)
5) Production costs assessed at $46:0 per tonne
6) X indicates that control would not be economical

factors make costing on a 15 year basis very difficult but do not seriously affect a "short term" (two to three years) control method such as poisoning.

4.4 CONCLUSIONS

It is evident from the damage survey figures (after allowance has been made for palm compensation) that effective nut losses, even in areas of highest damage, do not exceed four to five nuts per palm per year. At these relatively low levels neither form of control would be worthwhile until the value of copra exceeded 150 dollars per tonne andin the case of banding would only apply in very limited situations. That is, palms would need to have grown sufficiently to have formed vertical trunks 10.5-12.0 m high (not achieved for tall palms until at least the 25th year), be evenly spaced and have no vegetation that could cause bridging of bands. Poisoning does not have such severe limitations, but a decision to control using this method has to allow for changes in the level of damage, copra yield and value over at least a two year period.

The final decision on whether or not to reduce rat damage must be governed by the size of the affected area and the overall efficiency of the plantation unit in addition to the level of damage, copra yield and value. Clearly where a percentage of the nuts are lost in secondary bush on the plantation floor, as occurs on some of Fiji's plantations, control is of little value.

Reduction of rat damage in Fiji coconut plantations would, in view of the number of variables, be of marginal value at current levels of damage. Only if the average level rose significantly and the value of copra remained at over 200 Fijian dollars per tonne would widespread control be economically sound.

RAT DAMAGE ASSESSMENT AND CONTROL IN COCOA

Chapter 5

5.1 INTRODUCTION AND REVIEW

Rat damage to cocoa in Fiji has received less attention than coconuts, despite apparently significant damage between 1900 and 1912 (Twyford and Wright, 1965). This early damage was purported to be the result of flying fox (*Pteropus sp.*) attack, but the virtual absence of such damage at present (Section 5.3A) makes it probable that rats were responsible. Jack (1936), Ffrench-Mullen (1944) and Yelf (1964) all noted rats were a problem in cocoa cultivation, but a major survey of the crop in 1959 (Harwood et al., 1959) did not mention the pest.

Rodent damage, caused by a considerable number of species from the families Sciuridae (squirrels) and Muridae (rats), occurs in most cocoa growing areas of the world. Montserin (1937) recorded losses in Trinidad of 2960 pods per hectare per year, about 30 percent of total production. Damage was caused by a tree rat, possibly *Rhabdomys sp.* Light to moderate damage (60-1060 pods/ha/year, 0.7-7.0 percent of the crop) occurred in Ghana, at Tafo (Glendinning, 1962) and in Eastern Regions (Taylor, 1961), while damage at Gambia, Nigeria, averaged 8.4 percent (Everard, 1968). Damage in West Africa is caused primarily by squirrels (*Protoxerus stangeri*, *Heliosciurus gambianus*, and *Funisciurus spp.*) and the giant or pouched rat (*Cricetomys gambianus*).

Rat damage is serious in some Pacific Islands with losses of 40 percent being recorded in the Solomon Islands (Friend, 1971) and the Caroline Islands (Strecker and Jackson, 1962). Damage also occurs in the New Hebrides (Urquart, 1953) and Western Samoa (personal observation).

Although cocoa has been grown in Fiji since 1890 and rat damage has apparently been present since the start of cultivation, the problem probably failed to attract attention until recently because the cocoa bearing acreage was insignificant (less than 40 ha). However, by 1965 the bearing area had increased to about 500 ha and rat damage was known to be serious in some localities (Yelf, 1964). No formal studies were made in 1964 because low world prices and poor yields, due to disease, had reduced interest in the crop.

By the late 1960's the better yields of Amelanado, coupled with rising world prices, led to renewed interest in the crop and initiation of a general cocoa research programme in some localities (Vernon pers. comm.). In view of the potential of the crop it was considered essential that rat damage and control techniques be investigated in some detail, hence the incorporation of cocoa damage into the overall rat research programme.

5.2 SURVEY METHODS

The Cocoa section of the Fiji Department of Agriculture Research Division began production and damage recording at four sites in 1968, as part of an overall study of the cocoa crop.

In the trials, which investigated fertiliser. shade and spacing requirements, pod production was recorded as:-

a) Useable: those pods sold for processing

b) Damaged by black pod: a disease, caused by the fungi Phytophothora palmivora, which turns the developing pod black.

c) Damaged by rats; with ahole chewed in the side of the pod and the beans removed (Figure 5.1).

Recording was usually at weekly intervals and there was virtually no overlap between the two damage categories. All pods with holes chewed in the side were classified as rat damaged, even if a limited amount of black pod was present, as rats do not appear to attack ripe pods sufficiently diseased to make them unuseable. Most black pod occurs while the pods are still green, a feature that further reduces the interaction of the two damage categories. Useable and damaged pods were recorded for various numbers of sub-plots at the four sites but the rat damage data for these was aggregated to form a total for the whole site as the plots were too small (i.e. $<$0.1 ha) for damage to reflect rat population levels within them.

The four experimental sites established by the Cocoa Research Section incorporated larger areas of cocoa than that cultivated by most farmers, so it was essential also to investigate rat damage on small holdings. Therefore eight plots were established in the main cocoa areas on Vanua Levu and Viti Levu and production recorded for various periods from July 1970 to June 1971 using the criteria as outlined above. The incidence of black pod was recorded on the small holdings to augment general cocoa research in Fiji, but since black pod damage did not interact with rat damage, it has not been included in this description of the investigation.

5.3 RESULTS

5.3A Features of Rat attack on Cocoa and Species Responsible

Rats mostly attack cocoa as it reaches maturity, indicated by

FIGURE 5.1

RAT DAMAGED COCOA POD WITH ALL BEANS REMOVED

a colour change, but immature pods are occasionally attacked when few ripe ones are available. Although most of the cocoa beans are removed from pods attacked, the sweet mucilage surrounding the bean is the only part eaten. The pod shell usually remains on the tree until the husk dries or rots away.

All pods penetrated by rats represent a net production loss because damage is concentrated on mature fruit and there is therefore no time for the cocoa tree to compensate for damage. This contrasts with rat attack of coconuts which occurs some months before the nuts are mature, thus allowing time for compensatory mechanisms to operate (Section 3.4).

All three species of rat present in Fiji were trapped on cocoa farms but their distribution and relative abundance varied considerably (Figure 2.15). R. exulans and R. rattus were trapped frequently in the first fork of cocoa trees while R. norvegicus was seldom caught in the arboreal sector of the habitat (Table 2.8).

Rattus teeth marks on freshly damaged cocoa pods were examined using the techniques described for coconuts (Section 3.2B). Pods collected at the Namara Road survey site during 1971 and 1972 indicated that approximately 90 percent (n = 104) of the damage was caused by R. rattus. Aspects of this difference between species are discussed in Section 5.3C.

Cocoa pods attacked by flying foxes were observed on the islands of Kadavu and Vanua Levu but the total damage caused by this species appeared to be insignificant.

5.3B Damage Levels

Although rat damage was surveyed on the larger plantations from 1969 to 1971 (Table 5.1) data does not include all years at all sites as rat poison was laid during some years and

Table 5.1 RAT DAMAGE AND PRODUCTION ON RESEARCH PLANTATIONS AND LARGER ESTATES

Island	Plantation	Area under Cocoa (ha)	Years Recorded	Pods per hectare per year			Rat damage as a percentage of total production
				Rat damaged	Useable	Total production	
Viti Levu	Waimaro	1.7	1970	4,600	21.600	26,200	17
			1971	9,500	30,500	40,000	24
Vanua Levu	Wainigata	2.8	1969	5,800	23,400	29,200	20
			1970	6,900	22,000	28.900	24
Taveuni	Delaiweni	-	1968	370	3,830	4,200	9
			1969	3,200	1,900	5,100	64
Viti Levu	Wainibuka	-	1969	2,100	21,900	23,900	9
			1970	3,500	30,100	33,600	10

recording had to be terminated during others, for reasons beyond the Research Division's control. Data for small holdings (Table 5.2) has not beeen expressed on a per hectare basis as the spacing, amount of shade and general plantation management varied greatly from farm to farm.

Despite these recording differences there was clearly considerable interfarm variation in damage levels particularly on the small properties (Table 5.2). The low level of damage on some farms was probably related to the numbers of R. rattus present, since this species appears to be responsible for most of the damage. There was also limited evidence to suggest that damage levels were dependent on the length of time rats have been associated with the crop (Section 5.3C) This could mean that rat damage might not become serious until ripe pods had been present for one or more seasons.

Damage on the larger properties was consistently higher than on the small holdings with damage at all sites exceeding 3000 pods per hectare on one or more years and damage at Waimaro in 1971 reaching 9490 pods per hectare. These levels of damage were similar to those recorded by Friend (1971) on Government Cocoa Research plantations in the Solomon Islands.

5.3C Distribution of Damage and Possible Reasons for Attack

There were marked fluctuations in rat damage during the harvesting season at most sites, an aspect particularly apparent at Waimaro and Wainigata during 1970 (Figure 5.2). These fluctuations were caused by a general correlation between the number of ripe pods present and the amount of damage. Such a relationship could be expected if even a proportion of a rat population was actively seeking ripe cocoa pods, because with a constant pattern of foraging such animals would locate more ripe pods as the number increased. Nevertheless the number of

Table 5.2 RAT DAMAGE AND PRODUCTION ON SMALL HOLDINGS

Island	Plantation	Number of trees	Start of recording period	Number of days	Number of pods			Rat damaged as a percentage of total production
					Rat damaged	Useable	Total production	
Vanua Levu	Wailevu	350	July 1970	457	50	12,440	12,490	0.4
"	Nagigi	350	July 1970	351	3,320	5,820	9.140	36
"	Natewa Bay	350	August 1970	446	2,360	4,900	7,260	33
"	Navonu	450	July 1970	421	320	8,505	8,370	4
"	Loa	750	July 1970	478	4,660	15,920	20,580	23
Viti Levu	Navua	300	October 1970	359	2,290	6,220	8,510	27
	Namara Road	302	June 1971	462	970	6,750	7,720	13
	Wainibuka	144	April 1971	127	60	3,040	3,100	2

FIGURE 5.2

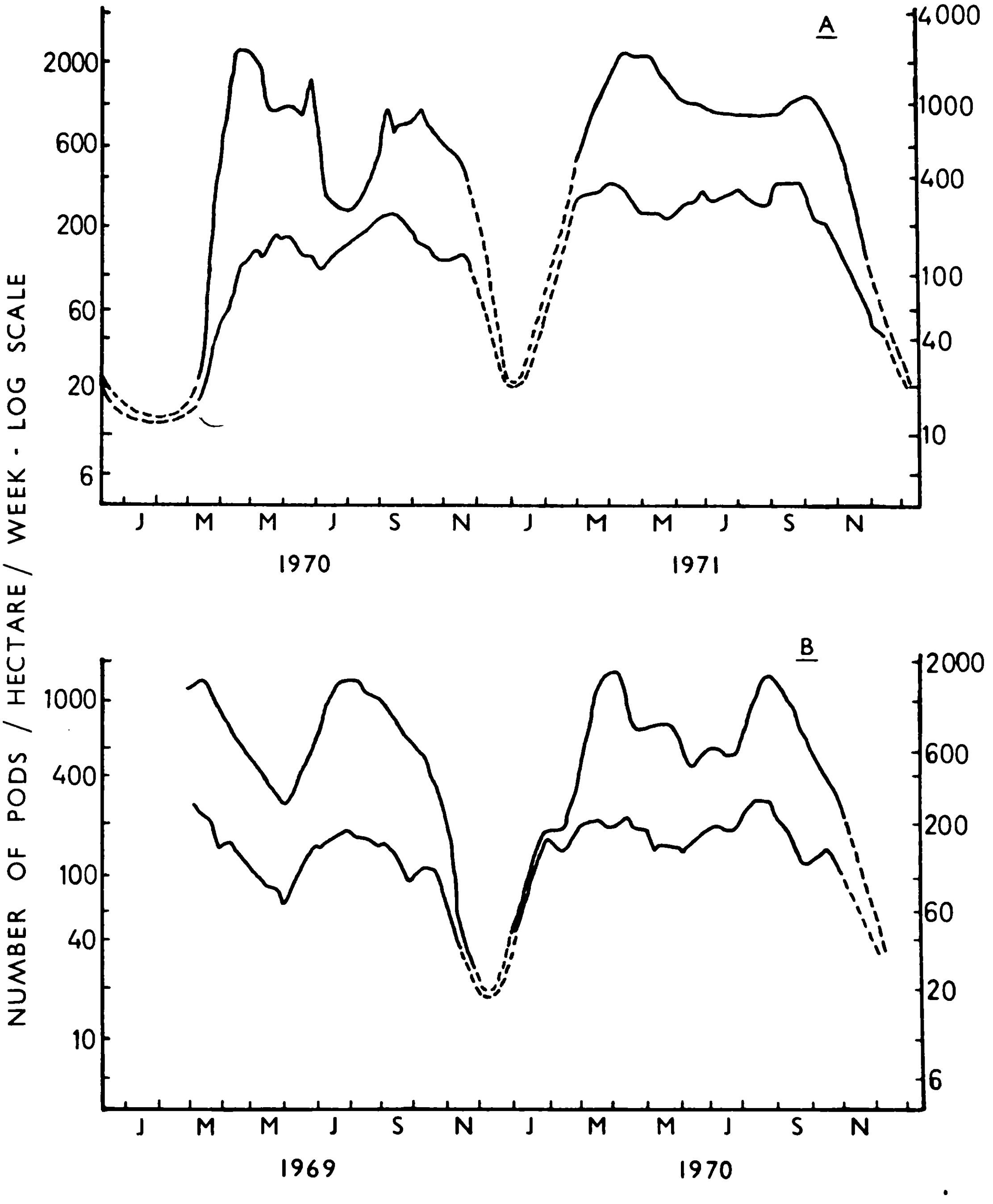
SEASONAL FLUCTUATIONS IN RAT DAMAGE AT TWO SITES

A = Waimaro Research Station

B = Wainigata Research Station

Upper line = Total useable and rat damaged pods recorded
Lower line = Number of rat damaged pods

Broken portions of both lines represent periods of little production and no recording


A
2000
600
200
60
20
6
4000
1000
400
100
40
10
J M M J S N J M M J S N
1970
1971
B
1000
400
100
40
10
2000
600
200
60
20
6
J M M J S N J M M J S N
1969
1970
NUMBER OF PODS / HECTARE / WEEK - LOG SCALE

ripe pods can greatly exceed the populations capacity, particularly at harvest peaks (Figure 5.2; Wainigata, April and September 1970).

In the latter part of the harvest season (i.e. July 1st to September 30th, Table 5.3) there was an increase in the number of ripe pods damaged despite a decrease in the number of ripe pods available (difference column, Table 5.3). This suggested that there were either more rats present later in the season or that more individuals were seeking ripe cocoa.

Population studies at the Namara and Grenada sites (Figure 2.31 and Figure 5.3) indicated that there was little relationship between damage levels and the number of rats present but as with rat attack of coconuts the availability of other sources of food must also affect the level of rat damage to cocoa (Section 2.5C). In addition the assessed population at both these sites consisted almost entirely of R. exulans which, as noted above, appeared to cause little damage. At Waimaro station there were insufficient recaptures to allow the rat population to be estimated by one of the more sophisticated methods. Nevertheless relative estimates of R. rattus, R. exulans and R. norvegicus numbers suggested that the average level of damage was higher during years when R. rattus populations were at higher levels (Figure 5.4), a finding that was consistent with this species' preference for the crop. The number of R. norvegicus present appeared to have no impact on the level of damage and the apparent disappearance of this species from the cocoa at the end of 1970 may have permitted the increase in the number of R. rattus during 1971.

Although there was an apparent relationship between R. rattus numbers and the level of damage, there were no

Table 5.3 SEASONAL CHANGES IN THE PROPORTION OF PODS RAT DAMAGED

Plantation	Pods	Harvest periods		Difference between periods
		1 April - 30th June	1 July - 30th Sept.	
Wainigata	Harvestable	28,488	24,060	-4,428
1970	Rat damaged	6,965	7,009	+ 44
Waimaro	Harvestable	24,323	4,757	-19,566
1970	Rat damaged	2,665	3,337	+ 672
Waimaro	Harvestable	28,190	12,543	-15,647
1971	Rat damaged	5,435	6,062	+ 627

FIGURE 5.3

THE EFFECT OF POISON APPLICATIONS ON THE *RATTUS* POPULATION AND THE NUMBER OF COCOA PODS RAT DAMAGED AT THE GRENADA BLOCK, WAINIGATA RESEARCH STATION

Upper line	= Number of rats in grid area
Open circles	= Useable pods, four weekly running means
Solid circles	= Rat damaged pods, four weekly running means
Horizontal lines	= Periods when poison laid

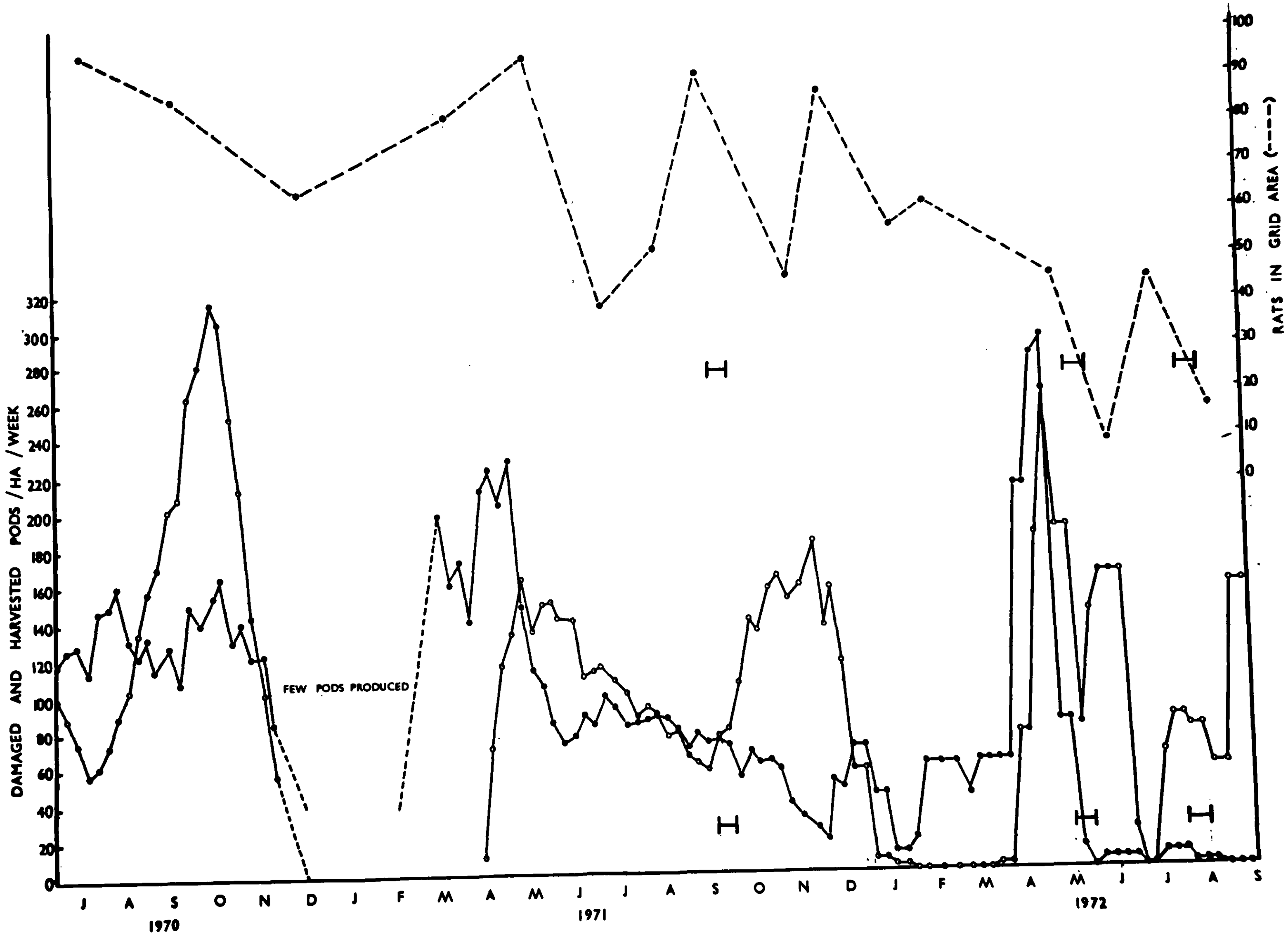
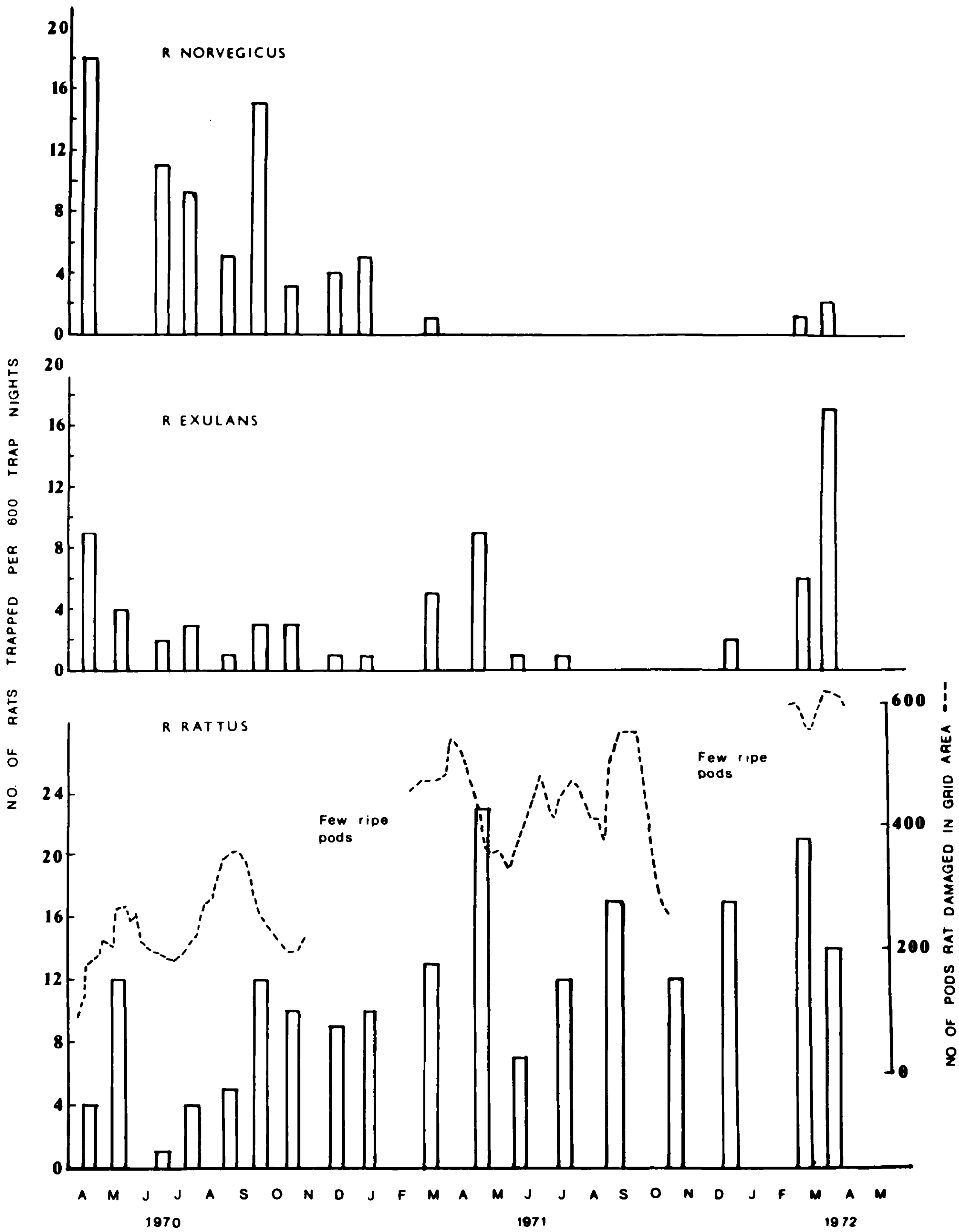

RATS IN GRID AREA (----)
DAMAGED AND HARVESTED PODS / HA / WEEK
FEW PODS PRODUCED
J A S O N D J F M A M J J A S O N D J F M A M J J A S
1970
1971
1972

FIGURE 5.4

THE RELATIVE NUMBER OF *R. RATTUS*, *R. EXULANS* AND *R. NORVEGICUS* AT WAIMARO COCOA RESEARCH STATION, AND THE POSSIBLE RELATIONSHIP BETWEEN *R. RATTUS* NUMBERS AND THE LEVEL OF DAMAGE TO COCOA

Broken line represents the number of pods rat damaged per week in grid area (1.7ha).



R NORVEGICUS
R EXULANS
R RATTUS
NO. OF RATS TRAPPED PER 600 TRAP NIGHTS
NO OF PODS RAT DAMAGED IN GRID AREA
Few ripe pods
Few ripe pods
0
4
8
12
16
20
24
200
400
600
A M J J A S O N D J F M A M J J A S O N D J F M A M
1970
1971
1972

population increases towards the end of any harvest season, that could have caused the distinct rise in damage. A possible explanation for this rise was that within the population there were more individuals attacking cocoa towards the end of the harvest season.

Cage studies indicated rats do not always attack ripe cocoa even if they have been in contact with the crop for some time. Nine R. exulans were trapped in a cocoa grove and, after a period of familiarisation with individual cages, ripe cocoa pods were placed in the cages in addition to their normal diet of padi rice and commercial poultry pellets. Only one pod was attacked over a period of seven days. Another group of R. exulans, born in captivity, with no contact with cocoa, were subjected to identical experimental conditions. No pods were attacked over the same period of time. In contrast, four out of seven R. rattus trapped in a cocoa grove attacked pods presented under the same experimental conditions, as the above groups of R. exulans.

Although the trial was of a very limited nature it does suggest, apart from the fact that R. exulans does not appear to favour cocoa, that not even all R. rattus in a cocoa grove population are aware that edible sweet mucilage exists within a cocoa pod. They appear to have to learn of its presence, either by trial and error gnawing on cocoa pods (a few pods in the cage trials showed signs of gnawing) or feeding on pods opened by an experienced rat. The outer shell of a cocoa pod is extremely bitter and the size and shape of the pod particles discarded by an attacking rat indicated they did not favour the shell.

As each cocoa season progressed more individuals in a population probably learn that the mucilage is edible, hence the rise in damage (Table 5.3).

Everard (1968) found that squirrels and rats attacking cocoa in Nigeria had to learn there was sweet mucilage within a pod and inexperienced animals under cage conditions had to be introduced to open pods before they would attack unopened ones. The apparent necessity to learn that a crop is edible has also been reported in relation to rat attack of corn (maize) in the Tongan Islands (Yamada pers. comm). Attack seldom occurred until cattle, bird or pig damage exposed ripe cobs. Following such an "introduction" the amount of rat damage increased rapidly, in its absence damage was often low.

The sugar content of coconuts appeared to be the basic nutrient attracting rats to the crop (Section 3.2C) and this would also appear to apply to cocoa, even though no attempt was made to measure the sugar concentration in the favoured mucilage. Cocoa pod mucilage cannot be an important food for most rats in a cocoa grove and for those that do attack cocoa the mucilage probably constitutes a "luxury" food of little importance to diet as a whole. Aspects of mammalian diet selection have been discussed in relation to rat attack of coconuts (Section 3.2C).

5.4 CONTROL

5.4A Methods of Reducing Rat Damage

Soon after the establishment of the general cocoa research programme in 1968, it was apparent that some method of reducing rat damage was necessary. Vernon and Sundaram (1970) compared the effect of harvesting ripe pods at various intervals, on the incidence of black pod disease. This disease was found to be partly controlled by the frequency of harvest. They also recorded the number of rat damaged pods as part of the overall survey (Table 5.4).

It was apparent that increasing the picking interval to four weeks caused a significant rise in rat damage, clearly making it advantageous to pick at the shorter intervals. The results of this trial are consistent with the behavioural features of rat attack discussed above; that is, if a given number of rats actively seek ripe cocoa the longer the pods are at risk the greater the chance that they will be located.

Although the harvesting of ripe pods at half weekly intervals reduced rat damage to 7.4 percent (Table 5.4) it involved too much labour and in addition communal collection of harvested cocoa was usually at weekly intervals. However rat damage at the practical picking interval of one week was, at 13 percent, unacceptably high so an investigation of rat control by poisoning was started in 1970.

5.4B Rat Control by Poisoning

I. Bait bases.

As outlined in Section 4.2B, legislation governing the use of poisons in Fiji prohibits, except under certain controlled conditions, the use of acute poisons such as zinc phosphide. For this reason all poison trails utilised the anticoagulant warfarin in combination with various bait bases.

The type of anticoagulant poison used is generally not as important in terms of overall efficiency, as the bait base with which it is combined, particularly in Fiji cocoa plantations where poisons have seldom been used. For good control it is essential that rats feed readily on the poison baits which means that they have to be more desirable foods than most others immediately available.

Table 5.4 THE EFFECT OF HARVESTING INTERVAL ON THE NUMBER OF PODS RAT DAMAGED

Harvesting interval	Number of pods			Percentage rat damaged (S.E.)
	Useable	Rat damaged	Total	
½ weekly	5,210	410	5,620	7.4 (±2.2)
1 weekly	5,180	780	5,960	12.8 (± 2.8)
2 weekly	3,270	730	4,000	16.4 (± 3.1)
4 weekly	2,750	810	3,560	22.4 (± 3.5)

Notes:- The 'total' excludes the black pods hence the apparent lower yield with longer harvesting interval.
- Each harvest interval was carried out on six plots of 30 trees each.

After Vernon and Sundaram (1970)

Bait base trials concentrated on testing commercial preparations that were available at a competitive price as it was difficult for the average farmer to mix baits that would prove consistently attractive to rats. In many areas of Fiji suitable bait bases are not readily available and few centres have supplies of paraffin wax required for the production of a waterproof bait.

A trial aimed at testing the palatability of two common bait bases, whole wheat and grain based meal, was carried out in a small isolated block at Wainigata Research Station. The plot consisted of 0.5 ha of cocoa and within this 46 regularly spaced bait stations were established. All stations were on the ground and consisted of a 'V' shaped metal sheet covering three dishes which contained the baits. The trial was run for 10 days and baits were weighed daily to determine the amount eaten by rats. The number of slugs and snails on each bait type was also recorded and all animals were removed at least 5 m from each bait station.

Rats (R. exulans and R. rattus) clearly favoured bait B of which significantly more than A ($t = 8.5$, $p \Rightarrow 0.001$) or C ($t = 2.7$, $p => 0.05$) was consumed (Table 5.5). The higher consumption of bait B could have been partly due to the significantly higher slug and snail infestations on the other two baits (A/B, $t = 5.1$, $p > 0.001$; B/C, $t = 2.1$, $p => 0.05$). Nonetheless the very marked difference between the consumption of baits B and D indicated that rats did not favour the latter preparation. In the absence of slugs and snails bait A would probably have proved as palatable as bait B.

The total amount of bait consumed during the 10 days was 11.5 kg (9.6 kg per ha.) which was a high level of consumption and

Table 5.5 THE COMPARATIVE ACCEPTABILITY, AND SLUG AND SNAIL INFESTATION RATE OF THREE BAIT TYPES IN A COCOA PLANTATION

Bait	Description of Bait	Total weight of bait eaten Kg (S.E.)	Total number of slugs and snails removed from baits (S.E.).
A	"Crest" pigmeal mixed with fat, sugar and sufficient wax to form a block. (experimental block, 0.025% warfarin)	4.1 ($\pm$ 0.28)	1029 ($\pm$ 120)
B	Whole wheat grains impregnated with warfarin (0.05%) and set in sufficient paraffin wax to hold the grains together. (commercial block, produced by Rentokil Ltd. Auckland)	5.4 ($\pm$ 0.40)	743 ($\pm$ 60)
D	Fine wheat germ meal combined with excess paraffin wax to form a hard block. (commercial block, 0.025% warfarin, produced by Messrs Geigy Agchim, Paris).	2.0 ($\pm$ 0.09)	1211 ($\pm$ 74)

probably reflected the shape of the cocoa block as well as the locality. The grove consisted of a narrow strip located on a stream flat, surrounded by bush and reed covered terrain. Poison laid in such a block probably kills animals over a larger area than that in which it is actually laid (see below), thus the consumption in relation to cocoa area tends to be higher than in a larger block.

To summarise; this multiple choice bait trial suggested that bait B was superior to either baits A or D but that in the absence of slugs or snails bait A could prove as palatable as B. A subsequent trial, described below, confirmed this and indicated that the meal based bait was an alternative to the commercial preparation, when the ingredients could be obtained.

II. Bait spacing, siting and application rate.

To investigate the various aspects of practical rat control in cocoa all of Waimaro Research Staion (1.7 ha) and most of Wainigata (2.8 ha) was systematically treated with poison after the recording of rat damaged and harvestable pods had been completed. In addition several of the farmers properties (Table 5.2)were treated.

By the end of 1970 *Rattus* movement studies (Section 2.4B) had indicated that 15-.30 bait points per hectare would ensure that even rats with a restricted home range came in contact with at least one bait station The existence of social hierarchies within a rat population (Calhoun, 1962), which results in subordinate animals initially being excluded from feeding sites, also precludes very widely spaced baits.

As. *R. rattus*, the species causing most damage, moved predominantly within the cocoa trees (Section 2.4C) most baits were placed in the first jorquette.

Application of sufficient poison to achieve optimum control, with a minimum of waste, is one of the most important aspects of any form of crop protection. Therefore poison baits were applied at several rates on the two research stations and farmers properties. Three bait types were used during these trials, type A and B as per Table 5.5 and type C as described in Table 5.6.

At Wainigata during 1971 bait types A,B and C were paired (A-B, B-C) to compare bait acceptability and the ease oflaying the three preparations. In March 1971 each bait type was laid at alternate stations (i.e. 33 out of the 66 sites) with two 115 gm baits at each point, one in the first jorquette of the cocoa, the other on the ground In October both bait types were placed at all 66 stations with bait B (115 gm blocks) in the first jorquette and bait C on the ground in bamboo tubes .

More of bait A was eaten (11.4 kg) than either of the other two and was not affected by slugs or snails when placed in the first jorquette (Table 5.6). The low consumption of bait C possibly reflected an excess of bait stations but could also have been a manifestation of the vertical distribution of Rattus species since bait C was placed only on the ground. Bait B was the most convenient to use as it required no preparation and was easy to attach to the trees. Bait A had to be prepared from raw materials, a time comsuming task, and because the resulting wax block was much softer than bait B it was more difficult to attach to trees. To keep bait C dry it was necessary to place it in bamboo tubes. These tubes had to be cut from the bush and distributed through the cocoa two operations that required considerably more labour than the simple distribution of bait B.

At Wainigata and Waimaro during 1972 all treatments used bait B as it had proved to be the most suitable preparation

Table 5.6 THE CONSUMPTION OF POISON BAIT ON RESEARCH PLANTATIONS AND SMALL HOLDINGS

Plantation	Date Laid	No. of days bait in position	Bait type & wt. Laid (Kg)			Bait types & wt. Eaten (Kg)			Total bait wasted (KG)	Total bait eaten (Kg)	Total bait laid, Kg per hectare
			A	B	C	A	B	C			
Wainigata (2.8 ha)	29-3-71	15	17.6	12.0	-	11.4	5.8	-	12.4	17.2	7.0
	14-10-71	15	-	9.4	4.9	-	7.2	3.6	3.5	10.8	5.1
	2-3-72	15	-	8.7	-	-	7.7	-	1.0	7.7	3.1
	12-6-72	14	-	6.8	-	-	6.0	-	0.8	6.0	2.4
	11-9-72	14	-	5.8	-	-	4.5	-	1.3	4.5	2.1
Waimaro (1.7 ha)	14-4-72	35	-	14.4	-		12.2	-	2.2	12.2	8.5
	4-9-72	17	-	10.7	-	-	8.4	-	2.3	8.4	6.3
Loa	12-10-71	14	-	3.2	1.5	-	3.0	1.5	0.2	4.5	-
Navonu	21-10-71	14	-	2.3	1.1	-	1.8	0.9	0.7	2.7	-
Nagigi	10-11-71	14	-	2.8	2.5	-	1.4	2.1	1.8	3.5	-
Serua-Namosi	14-10-71	17	-	5.7	2.3	-	4.9	1.5	1.6	6.4	-

Note: Bait types A and B as per Table 5.5

Bait type C = Commercial preparation of whole wheat impregnated with 0.05 percent Warfarin (produced by Rentokil Ltd., Auckland).

readily available (Table 5.6). At Wainigata bait station density was reduced to approximately 16 per hectare in an attempt to reduce baiting labour. In addition the weight of baits was reduced to 57 g per station to limit the amount of waste, that is the amount of bait remaining after most of the resident animals have been killed. The reduction in bait size successfully reduced waste (Table 5.6) but entailed more frequent checking of baits to ensure that all stations had a supply at all times.

Thirty baits per hectare, with an initial application of 115 g per station, were used at Waimaro during 1972. Waste was higher than at Wainigata but was still at an acceptable level (Table 5.6).

Total bait consumption was considerably higher on both research stations at the first application, 2.5 kg per hectare at Wainigata in 1971 and 2.0 kg per hectare at Waimaro in 1972. At both stations the consumption declined at subsequent treatments, to as little as 0.64 kg per hectare on the third application at Wainigata in 1972.

Commercial baits B and C were also tested on four small holdings and on three of the four bait B was eaten in greater quantities than C (Table 5.6). Bait wastage was not excessive on any of the farmer's properties and would have been lower at Nagigi and Serua if bait C had not been used. Total consumption, ranging from 1.8 to 3.0 kg per hectare, was similar to the initial application on larger research station plantations.

III. The effectiveness of poison applications

The Grenada Block population study (site and procedures described in Section 2.2) was established primarily to investigate the impact of a poison programme on a *Rattus* population (and therefore control efficiency) within a cocoa grove. A regular capture-recapture trapping programme was carried out from July 1970 until September 1971 as well as weekly harvesting of all mature and rat damaged cocoa. The number of rats present was estimated using the method of Manly and Parr (1968) which was discussed in Section 2.5C.

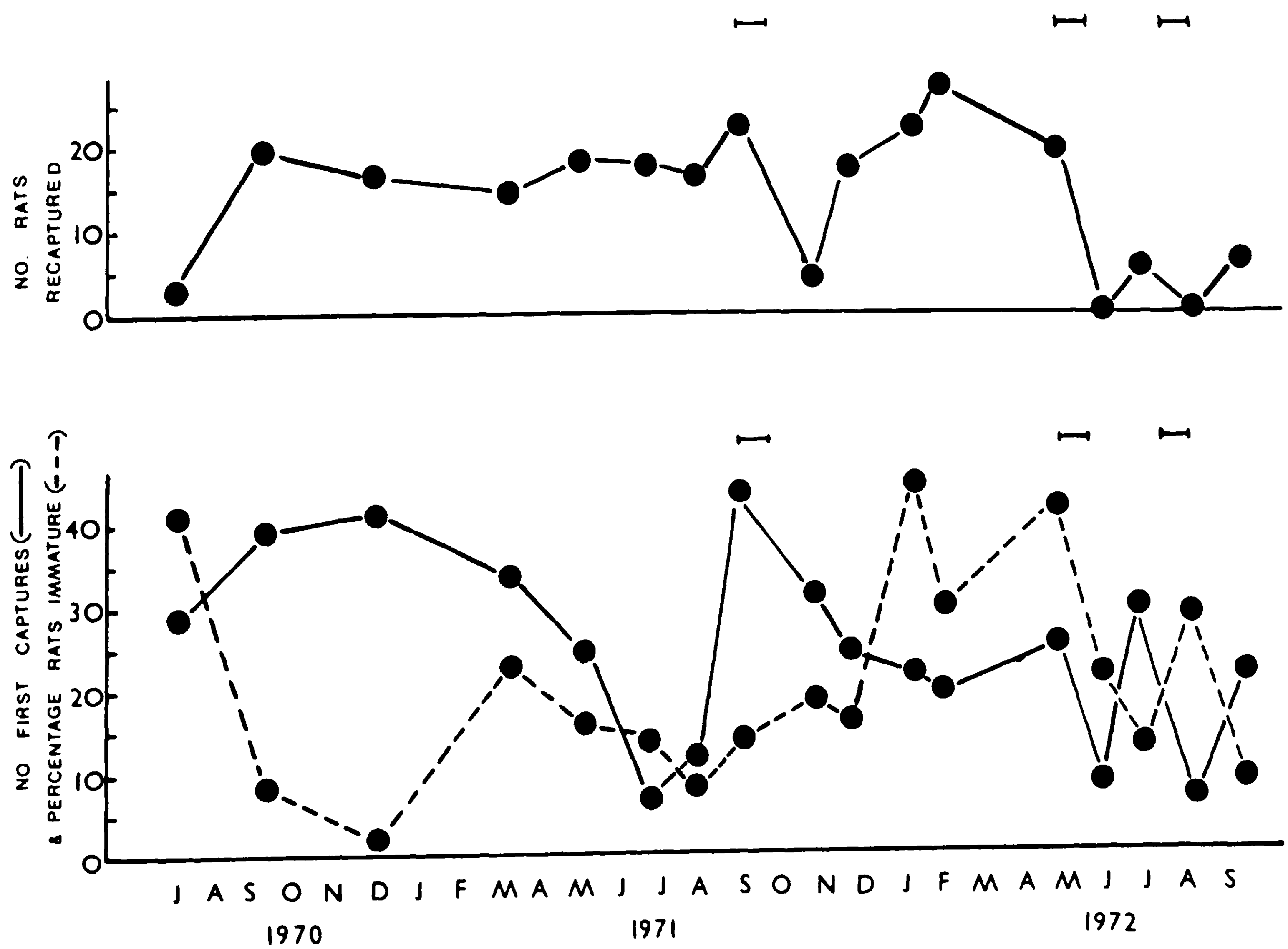
During September 1971 the block was poisoned with bait B. Baits were placed in the first fork of trees and on the ground at approximately 25 sites and kept in place for 14 days. Despite a bait consumption level of 6.6 kg per hectare there was only a slight and temporary decrease in the level of damage the week after poisoning was started (Figure 5.3), although there was a marked decrease in damage during November which could not really be attributed to the effect of the poison. This latter decrease could have been the result of an abundance of other foods, a feature discussed in Section 2.5C.

Live trapping was commenced four weeks after the completion of poisoning and revealed, as had the level of damage, a substantial population of both R. rattus and R. exulans (Figure 5.3). However, only 5 of the 37 rats captured had been caught prior to the laying of poison (Figure 5.5). These five animals had been first caught at the September trapping, immediately before poisoning, and all in traps on the periphery of the grid. This suggests they were new arrivals to the area and spent little time foraging in the cocoa, hence they escaped being poisoned. The relatively large number of new animals (mostly adults) in the cocoa block only four weeks after poisoning indicated a very rapid rate of invasion from the surrounding terrain, a movement that was undoubtedly enhanced by a general increase in rat populations during the period August to December 1971 (Figure 5.3). The percentage of immature rats caught during the period January to May 1972 also indicated a general increase

FIGURE 5.5

THE NUMBER OF FIRST CAPTURES (UNTAGGED RATS) AND RECAPTURES (TAGGED RATS) CAPTURED EACH MONTH AND THE PERCENTAGE OF THE TOTAL THAT WERE IMMATURE AT THE GRENADA COCOA PLOT, WAINIGATA RESEARCH STATION.

Horizontal lines = periods when poison laid


NO. RATS RECAPTURED
0
10
20
NO FIRST CAPTURES (——)
& PERCENTAGE RATS IMMATURE (- - -)
0
10
20
30
40
J A S O N D J F M A M J J A S O N D J F M A M J J A S
1970
1971
1972

in the level of breeding (Figure 5.5).

In an attempt to reduce the rat population in the area immediately surrounding the cocoa, and thereby reduce the reinvasion rate, applications of poison during May and August 1972 were extended approximately 10 m beyond the cocoa perimeter. Trapping two weeks after the completion of poisoning in May caught only nine new rats and none previously captured (Figure 5.5). By mid-July, six weeks after the completion of poisoning the population had risen considerably as 30 new arrivals were captured (Figure 5.3 and 5.5). Following the August poisoning trapping one and six weeks later revealed a very similar rate of reinvasion although the total numbers were lower, probably due to the apparent absence of much breeding during the period in combination with the general depletion of the rat population in the area surrounding the cocoa.

Only a small proportion of the trappable rat population survived any of the poison applications, suggesting that most of the rats normally resident within the cocoa were killed. However, the reduction of damage to cocoa is evidently dependent on rat population trends at the time of poisoning. If the population is building up, rapid reinvasion occurs and the effect of poisoning may be short lived. In contrast, a population poisoned during a period of decline (January to May 1972, Figure 5.3) is slow to recover and hence the reduction in damage is much greater.

While the Grenada population and poison trial indicated that a high proportion of the rat population was accepting the poison bait, the known wire trap avoidance behaviour of _R. rattus_ (Section 2.4) could have obscured bait avoidance by _R. rattus_. Therefore to determine the percentage of a rat population that accepts poison preparations, bait dyed with fluroscene which can be detected under an ultraviolet light, was used in a trial at the Namara Road population survey site (Section 2.2A). At the completion of the population study, in September 1972, 63 percent of the rats normally resident within the 1.2 hectare cocoa plantation carried a numbered ear tag (Appendix 3) and an estimate of the total population was available (Section 2.5C).

A bait similar to type B (described above) was formulated using padi rice, paraffin wax and the dye. It was laid as 60 g blocks in the first jorquette at 54 sites within the cocoa. Four days after bait laying two break-back traps were placed at all sites, one on the ground, the other in the first jorquette. Trapping was continued for nine days and within that period 121 rats (11 R. rattus and 110 R. exulans) were caught. All the R. rattus and 87 percent of the R. exulans had eaten the bait (i.e. gut contents contained traces of the dye) indicating that most resident rats should have been poisoned over the 13 day period. This conclusion assumes that the sample of animals trapped was representative of those feeding on the dyed bait and that the amount ingested constituted a lethal dose.

This trial also indicated the effect a poison programme has on the rat population in the terrain immediately surrounding the poisoned area. During the first four days 50 percent of the animals caught had ear tags and were therefore normal residents of the area, but in the final four days of trapping only 23 percent of the rats trapped were tagged, indicating that rats were already migrating into the cocoa as the resident population was reduced.

The rate of reinvasion clearly had an affect, indicated by the degree of reduction in the number of damaged pods, on the efficiency of poisoning at most of the sites treated (Figure 5.6). Treatments at Waimaro were more effective than at Wainigata with losses per hectare per week at the former not exceeding 37 pods after the first application, while at the latter they reached 99 pods. The shape of the plantations were probably responsible for the apparent differences. Waimaro was basically a 1.7 hectare rectangle surrounded by grazed pasture, stream flats, and weed-filled small gullies, while Wainigata cocoa block consisted of a long narrow 2.8 hectare strip bordered by a stream and well maintained stands of young coconuts. Narrow plots with a high proportion of edge to centre would appear to be more rapidly re-invaded by rats and this could account for the lower poisoning efficiency at Wainigata despite the larger area treated. Treatments during the second year of poisoning at Wainigata reduced damage to successively lower levels, presumably as the reinvasion rate became successively slower (Figure 5.6).

Before the application of poison in April 1971 and 1972 substantial losses were incurred at Wainigata (1971) and Waimaro (1972). It seems that poisoning in Feburary, as at Wainigata in 1972, is essential to reduce the high level of damage early in the season. Two additional applications during the season, particularly before harvest peaks, would appear to maintain damage at low levels with each application being effective for approximately two months, on both large and small properties (Figure 5.6).

FIGURE 5.6

THE EFFECT OF POISON APPLICATIONS ON RAT DAMAGE TO COCOA AT FOUR SITES

A = Waimaro Research Station

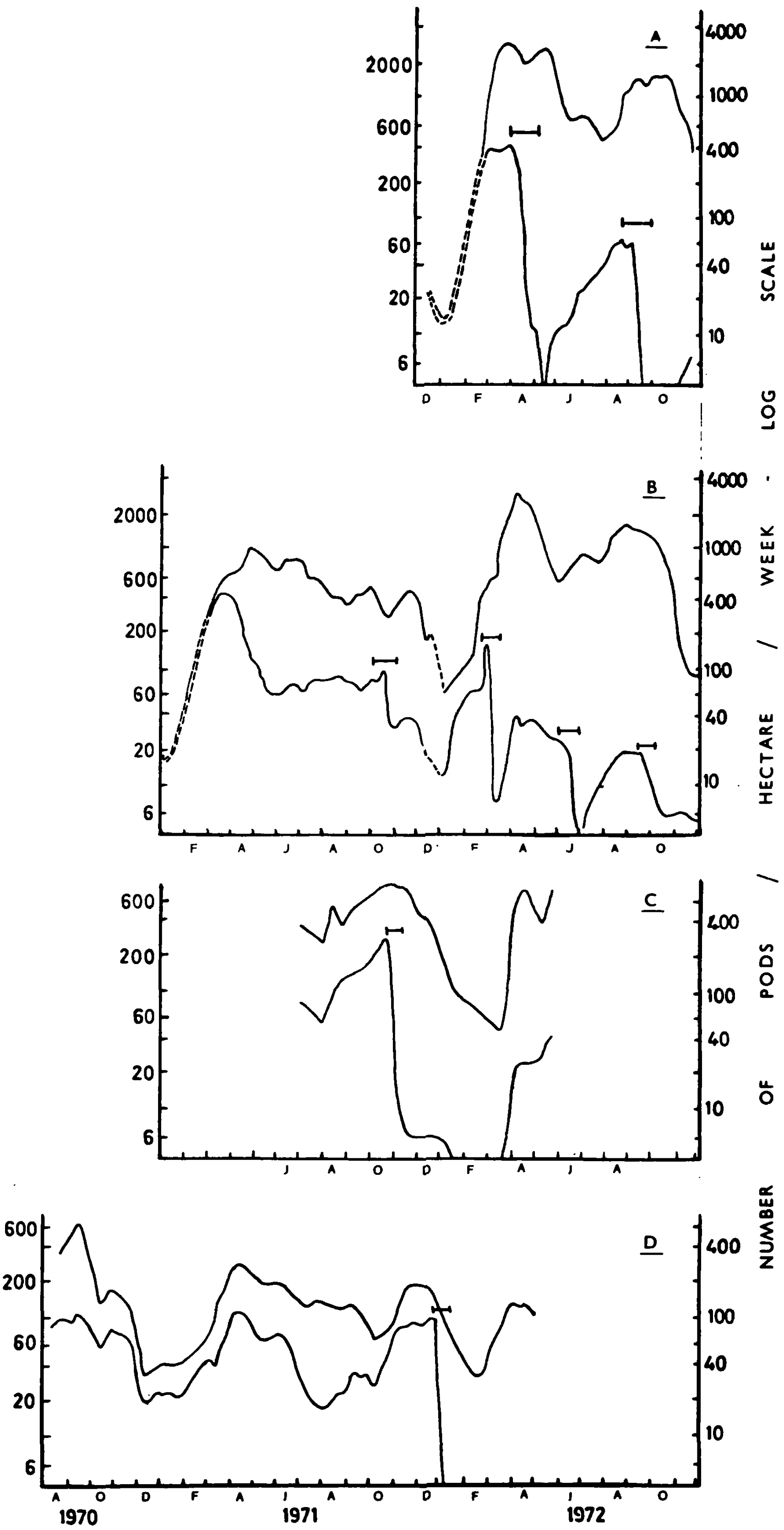
B = Wainigata Research Station

C = Cocoa Farm Loa

D = Cocoa Farm, Natewa Bay

Upper line = total useable and rat damaged pods recorded
Lower line = number of rat damaged pods

Horizontal lines = periods when poison laid.
Broken portions of both lines represent periods of little production and no recording



A
B
C
D
2000
600
200
60
20
6
4000
1000
400
100
40
10
D F A J A O
F A J A O D F A J A O
J A O D F A J A
A O D F A J A O D F A J A O
1970
1971
1972
LOG SCALE
NUMBER OF PODS / HECTARE / WEEK

5.4C Economics of Control

On properties the size of Waimaro and Wainigata it was evident that regular treatments using 2-4 kg per hectare per application were highly economic, while even on smaller properties the return on labour and invested capital made treatment well worthwhile (Table 5.7). Rat control became economic at those sites when damage exceeded three to four percent of total production but generally damage had to exceed five percent of total production to make control economical on well managed high producing properties. On small holdings percentage damage had to be higher to ensure control was economical as the efficiency of control on small plots tended to be lower than on large.

5.5 CONCLUSIONS

The reduction of cocoa yields by rats was clearly serious in some localities and it was evident that control should become an integral part of plantation management. The greater effectiveness of control programmes on larger plantations emphasised the importance of encouraging farmers, as far as soil and topography allowed, to plant cocoa in compact stands of as large an area as possible.

The commercial grain based poison bait was the most practical for general use and good control was achieved with applications of 2.1 to 3.1 kg per hectare per treatment (Wainigata, 1972), distributed to as few as 16 bait stations per hectare. To achieve the best level of control the first application was required at the begining of the harvest season, with an additional one to two applications later in the season.

Table 5.7 ECONOMICS OF RAT CONTROL IN COCOA PLANTATIONS

Plantation	Pre-treatment loss of pods (percentage)	Treatment periods	Production during treatment periods, pods per ha.				Control costs and benefits. (F$ per hectar	
			Total pods produced	Expected loss at pre-treatment rate	Actual loss during treatment period	Diff. between expected and actual loss (value F$)*	Cost of+ control	Net Savings
Waimaro	20	9-4-72 to 27-9-72	26,121	5,224	860	4,360(43.60)	8.65	35.00
Wainigata	22	2-3-72 to 25-9-72	20,087	4,419	371	4,048(40.48)	5.25	35.25
Loa	22	10-11-71 to 19-5-72	10,284	2,253	484	1,779(17.79)	4.05	13.75

Notes: * Pods valued at one cent each (1972)

+ Control costs included poison at 48.5 cents per Kg. and labour at 42 cents per hour.

The efficiency of this whole approach to damage reduction in cocoa is of course dependent on the absence of warfarin resistance within the <u>Rattus</u> population. As virtually no use has been made of anticoagulants in Fijian agriculture it is to be hoped that some solution to the problem of resistance can be developed before it does arise.

REVIEW

CHAPTER 6

The diverse studies described in this thesis sought to establish the importance of rats as pests of two crops, coconuts and cocoa. When the investigation was begun in 1969 there were several estimates of rat damage to coconuts being quoted, most based on casual observations only. In addition there were numerous novel ideas on rat behaviour. One such idea was that rats lived permanently in the palm crown, a feature of behaviour which was purported to invalidate the placement of aluminium bands since rats already in the palm crown could remain there.

In a study of this nature, where the breadth of investigation is considerable it is inevitable that some aspects of potential importance cannot be investigated fully. In this discussion an attempt will be made to highlight the major findings of the various studies as well as raise subjects that require further study.

Three species of Rattus were found to be present in Fiji with R. exulans and R. rattus being the most widely distributed. However as the study progressed it became apparent that the R. rattus populations were not being adequately sampled by the two types of cage traps used. There was clear evidence of marked trap-shyness by this species (Section 2.4A). This avoidance behaviour meant there were very few recaptures of tagged R. rattus, which resulted in an underestimation of the species in areas utilising live traps. Break-back traps appeared to sample R. rattus satisfactorily for the number of R. rattus captured in palm crowns was relatively high (Section 2.4C).

R. exulans and R. rattus made very different use of the vertical component of the habitat (Section 2.4C), particularly in coconut plantations. R. rattus was trapped regularly in tall palms (10-14 m high) but despite a ground population of R. exulans none of this species was caught in the crowns of palms over 10 m tall. This difference was not attributed to the competitive exclusion from palm crowns, of R. exulans by R. rattus, since the removal of R. rattus by crown trapping did not result in R. exulans moving into the crown sector of the habitat. Instead it was suggested that the vertical distribution of the two species reflected their innate climbing ability, for R. exulans was trapped in the crowns of short palms in the Salt Lake study area, as well as in short palms in Tonga (Whelan and Whelan, 1971), Tokelau Islands (Wodzicki, 1969) and the Marshall Islands (McCartney, 1970).

This vertical distribution of R. exulans and R. rattus had an important bearing on damage to coconuts by the two species. Because R. exulans did not forage in the crowns of tall palms the species was responsible for only a small proportion of the total rat damage to developing coconuts in the older plantations, typical of Fiji coconut growing areas. The investigation of teeth marks on freshly damaged coconuts clearly established that both species caused damage to cocnuts, but because of the height of the palms in most plantations R. rattus was responsible for damage (Section 3.2B)

R. rattus also appeared to be responsible for most damage to cocoa but the reasons for the apparent absence of R. exulans damage were not obvious. Trapping indicated that both species were frequenting the lower branches of the cocoa trees and the ground in approximately equal numbers at the Namara Road site (Table 2.8), but a survey of damaged pods indicated that R. rattus was causing most of the damage. This was an unexpected finding, for Strecker and Jackson (1962c) found that polynesia rats attacked cocoa pods in the Marshall Islands. Trials with caged rats during the present study, as well as by Strecker and Jacson (1962c) and Everard (1968) indicated that rats have to learn that there is sweet edible mucilage within cocoa pods. However it appears that there may be a behavioural difference between R. exulans and R. rattus response to strange food with the latter accepting new items more readily (Strecker and Jackson, 1962c). The rise in the percentage of pods damaged later in the cocoa harvesting season indicated that the number of rats learning to attack cocoa may increase relatively rapidly, although the percentage rise could have been partly due to rats favouring the sweet mucilage, seeking more ripe pods.

Why rats attack coconuts at all was a point of considerable interest. After it was established that damage was concentrated on coconuts aged three to seven months and there was a marked concentration of damage on particular palms (Section 3.3B), the investigation of nut sugar levels and husk hardness was carried out. Coconuts of the favoured ages had the highest levels of sugar (Nathanel, 1952) but there was found to be no difference between the sugar levels of nuts from palms favoured by rats versus those seldom attacked. Nevertheless there was a small difference in the husk hardness of the two categories of coconut and it was concluded that a combination of the two factors could account for the marked concentration of attack on particular palms. However in drawing this conclusion it had to be assumed that rats (R. exulans and R. rattus) did not find green coconuts of even the most favoured stages, a highly palatable food, for the difference in hardness between the most favoured and least favoured coconuts was relatively small.

Possible reasons for the concentration of attack on coconuts of particular palms is an aspect of rat behaviour that requires more detailed investigation. The analysis of sugar levels carried out during the present research programme was not entirely satisfactory. More critical analysis could well establish a difference between sugar levels or other nutrient elements in nuts of favoured and seldom attacked palms.

The significance of results from studies aimed at investigating the relationship between Rattus numbers and levels of damage were reduced by the trap avoidance behaviour of R. rattus. Nevertheless as approximately half the damage in the Salt Lake area was the result of R. exulans attack investigation of the relationships in this area proved valuable.

Rattus population densities reached relatively high levels on two occasions but it was evident from the overall level of damage that very few of even the R. exulans population could have been deriving a significant part of their daily food from green coconuts. This finding supports the conclusion drawn above, regarding the degree of motivation by rats to attack coconuts; it cannot be high or the level of damage, in view of population levels, should have been higher.

There was no correlation between the assessed population numbers at Salt Lake and the level of damage, the expected result in view of the fact that green coconuts comprised an insignificant component of the diet for most rats. However there did appear to be a relationship between the availability of other sources of food (as measured by the abundance of seasonal vegetation), the mean weight of adult R. exulans, and the level of damage to coconuts. It was concluded that coconuts are only damaged in larger numbers during population peaks that coincide with a general reduction in other possible sources of food (Section 2.5C).

While a number of aspects of the population dynamics of rats in Fiji were investigated, and it was established that major features of R. exulans reproduction and survival were similar to those recorded in other areas, considerably more information on population regulatory factors is required. The response of rats to various food items, or potential food items, within a habitat are also aspects of Rattus behaviour that warrant more detailed study, particularly in relation to cocoa since it appeared that R. rattus readily learns to attack ripe pods, while R. exulans, at least under some conditions does not (Section 5.3A).

The distribution and level of rat damage to coconuts varied considerably between survey sites as well as from month to month or even year to year. The overall level of damage, as distinct from loss, was found to be much lower (5.6 - 13.3 percent) than indicated by the best estimate made in the 1930's (28.0 percent; Paine, 1934).

Within any survey site damage was concentrated on a limited number of palms, but this did not cause a significant decrease in the number of harvestable nuts produced. This finding, first noted in 1970, led to the detailed investigation of the impact of rat damage on nut production.

It was postulated (Williams, 1971) that the coconut palm may be able to partly compensate for premature nutfall caused by rats as it mostly occurs before the developing nuts are six months old. The trial simulating four levels of rat damage produced one notable result, an increase in the number of female flowers in response to the premature loss of nuts. But because the development cycle of a coconut is a particularly long one (Figure 1.7) this response could not influence the number of harvestable nuts until at least 23 months had lapsed. However palms in the treatment sustaining the highest level of damage (D24) did not produce significantly fewer coconuts in the second year of the trial. Clearly some other compensatory mechanims, operating on a much shorter time scale, was effectively replacing the coconuts lost prematurely. The setting rate was investigated and it was found that the level of artificial damage had no apparent effect on this process. It was postulated that a change in the number of coconuts, over three months old, that were prematurely shed for reasons other than rat attack, may have allowed some of the simulated loss to be compensated for. Little data was gathered to support this hypothesis but results certainly indicated that relatively high levels of loss can be sustained by vigorous palms without a significant decrease in the production of harvestable coconuts.

Total compensation for loss does not seem possible for coconuts of the size classes favoured by rats contain up to 30 percent of the total dry matter content of a mature coconut, suggesting the upper limit for compensation is about 70 percent of the number of nuts prematurely lost. This conclusion assumes that a palm is always carrying the maximum crop available resources permit.

While it was evident from the trial, as well as field surveys, that palms were compensating for damage all the mechanisms involved were certainly not established and more work on this very important aspect of crop damage assessment is required.

In view of the number of variables influencing coconut production and possible mechanisms for compensation, it was concluded that palm response could be conservatively considered to compensate for 50 percent of a given level of rat damage. Thus all surveys of rat damage nuts were halved to derive figures representing actual loss. These loss figures were very low, being less than four nuts per palm per year at the survey site where the highest damage levels were recorded (Section 3.4).

The reduction of rat damage, by either poisoning or banding, was not economical at these low levels of loss, particularly as banding proved to be very inefficient on the shorter palms (trunk height of less than 10 m) that incurred the highest proportion of damage.

The investigation of rat damage to cocoa proved to be more straightforward than that of coconuts. As damage mostly occurred when pods were ready for harvest, all pods from which the beans were removed represented a total loss. Damage levels were relatively high on the larger properties with all sites exceeding a loss of 3000 pods per hectare on one or more of the years surveyed.

The warfarin impregnated wheat set in wax proved to be the most acceptable bait tested, and successful reduction of damage was achieved on all sites at which it was used despite the rapid reinvasion of the poisoned area by rats from adjoining terrain. Due to the high value of cocoa production per unit area, control using the commercial wheat based bait proved highly profitable (Figure 5.7).

The continued efficiency of poisoning Rattus populations in cocoa would depend on the absence of warfarin resistance. As up to three applications per year were required for efficient control resistance could become a problem relatively rapidly unless the use of warfarin could be interspersed with use of other rodenticides.

To conclude it is considered that the requirements of the overall investigation of rat damage in the two crops were met. That is, the level of loss in the two crops was determined as well as the efficiency and economics of available methods of reducing damage.

In addition a considerable amount of information relating to the general biology of the two predominant Rattus species was accumulated, as well as the way in which they interacted with the two commercial tree crops.

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APPENDIX I

PLANT SPECIES COMMONLY FOUND GROWING UNDER THE PALMS AT SALT LAKE, VANUA LEVU.

Common Name	Generic Name
GRASSES	
Airport grass	Chloris barbata (Linn.)Swartz
Barnyard grass	Echinochloa stagnina (Retz.) P. Beauv.
Batiki Blue grass	Ischaemum indicum (Houtt.) Merrill
Buffel grass	Cenchrus ciliaris Linn.
Korean Lawn grass	Zoysia japonica Steud.
Koronivia grass	Brachiaria humidicola (Rendle) Schweickt.
Mission grass	Pennisetum polystachyon (Linn.) Schult.
Para grass	Brachiaria mutica (Forsk.)Stapf.
Vetiver grass	Vetiveria zizanioides (Linn.) Nash
CITRUS	
Lemon	Citrus limon (Linn.) Burm.F.
Moli Kurukuru (F)	Citrus macroptera Montr.
Seville orange	Citrus aurantium Linn.
Sweet orange	Citrus sinensis (Linn.) Osbeck
WEEDS	
Blue Rat's Tail	Stachytarpheta urticaefolia (Salisb.)Sims
Centrosema	Centrosema pubescens Benth.
Clove	Eugenia caryophyllus (Spreng.) Bullock & Harrison
Denivuaka	Sida acuta Burm. f.
Ginger	Amomum cevuga Seem. (White Ginger, Cevuga)
Guava	Psidium guajava Linn.
Kaumoce	Cassia tora Linn.
Lantana	Lantana camara Linn. var. aculeata (Linn.) Moldenke
Mile-a-minute	Mikania micrantha H.B. & K.
Mint weed	Hyptis pectinata (Linn.) Poit
Qatima (Katema)	Urena lobata Linn.
Sensitive grass	Mimosa pudica Linn.
FERNS	
Fern	Dicranopteris linearis (Burm.) Underwood
Fern	Adiantum diaphanum Blume
Balabala	Cyathea affinis (Forst.) Swartz
Birds' Nest fern	Asplenium nidus Linn.
Kadakada	Microsorium scolopendria (Burm) Copel
Turalo	Tectaria degeneri Copel

APPENDIX II MARK AND RECAPTURE ANALYSIS FOR THE SALT LAKE *RATTUS* POPULATION BETWEEN JANUARY 1970 AND OCTOBER 1972.
(After Jolly, 1965, utilising the computer program of Davies 1971).

Year	Month	Time (I)	Proportion marked (alpha)	Total marked (M)	Total number (N)	Probability of survival (PHI)	Number joining (B)	S.E.(N)	S.E.(PHI)	S.E.(B)	Component of S.E.(N)	Component of S.E.(PHI)
	JAN	1		0.00		0.6682			0.1318			0.1120
	FEB	2	0.1795	30.74	171.26	0.8341	-5.14	59.22	0.1376	49.32	58.99	0.1293
	APRIL	3	0.3800	52.33	137.72	0.6840	76.80	27.66	0.0987	25.59	26.87	0.0845
	MAY	4	0.3333	57.00	171.00	0.7316	54.24	26.03	0.0756	21.85	25.05	0.0627
	JUNE	5	0.4505	80.47	178.61	0.7651	26.21	20.78	0.0718	16.75	19.28	0.0614
1970	JULY	6	0.6111	99.06	162.10	0.8726	11.23	17.72	0.0876	13.33	15.70	0.0824
	AUG	7	0.7246	110.00	151.80	0.7593	20.65	16.75	0.0879	9.86	14.54	0.0788
	SEPT	8	0.7059	91.12	129.09	0.6641	-13.33	14.42	0.0694	5.22	11.89	0.0529
	OCT	9	1.0192	73.80	72.41	0.7578	35.40	8.43	0.0795	6.57	3.62	0.0616
	NOV	10	0.6111	55.15	90.25	0.7537	8.91	10.83	0.0653	5.68	8.41	0.0427
	DEC	11	0.7460	57.40	76.94	0.8245	51.24	7.47	0.0661	7.03	3.54	0.0453
	JAN	12	0.4872	51.45	105.60	0.7844	35.58	9.99	0.0556	6.49	7.89	0.0353
	MARCH	13	0.6058	71.73	118.41	0.6372	43.39	8.42	0.0588	6.24	5.47	0.0372
	APRIL	14	0.6023	71.19	118.21	0.6993	43.87	10.51	0.0678	8.83	8.16	0.0507
	MAY	15	0.5823	72.86	125.13	0.7622	14.50	12.65	0.0770	8.23	10.68	0.0650
	JUNE	16	0.7344	80.68	109.87	0.7809	43.30	11.97	0.1022	14.62	9.68	0.0933
1971	JULY	17	0.5909	76.29	129.10	0.8400	4.70	19.95	0.1191	14.89	18.69	0.1130
	AUG	18	0.7000	79.20	113.14	0.8786	8.77	16.84	0.1505	13.73	15.22	0.1465
	SEPT	19	0.7407	80.13	108.17	0.7454	63.32	19.82	0.1228	18.80	18.46	0.1134
	OCT	20	0.4463	64.20	143.20	0.7979	8.54	20.95	0.0738	15.91	19.74	0.0614
	NOV	21	0.0250	76.75	122.80	0.8421	23.43	12.99	0.0645	9.47	10.69	0.0532
	DEC	22	0.6667	84.00	126.00	1.0286	80.83	11.15	0.1042	18.54	8.33	0.1056
	JAN	23	0.5287	108.00	204.26	0.5717	25.36	26.12	0.0652	13.03	25.04	0.0509
	MARCH	24	0.5977	84.61	141.55	0.7991	36.98	13.75	0.0712	9.79	11.00	0.0607
	APRIL	25	0.6289	92.38	146.91	0.7164	20.46	14.12	0.0861	8.95	11.56	0.0763
1972	MAY	26	0.7302	91.26	124.98	0.7341	22.82	15.87	0.1239	13.72	13.73	0.1205
	JUNE	27	0.6897	78.00	113.10	0.8489	16.14	21.54	0.1606	14.77	20.15	0.1560
	JULY	28	0.6585	73.86	112.15	0.6640	40.19	19.44	0.1134	13.55	17.93	0.1016
	AUG	29	0.5088	58.33	114.66	0.9545	74.47	17.51	0.1772	29.18	16.02	0.1757
	SEPT	30	0.8423	80.50	182.00			39.65			39.01	
	OCT	31	0.5309									

APPENDIX III MARK AND RECAPTURE ANALYSIS OF THE NAMARA ROAD RATTUS POPULATION BETWEEN JUNE 1971 AND SEPTEMBER 1972.
(After Jolly 1965. Utilising the computer programme of Davies 1971)

Year	Month	Time (I)	Proportion (Alpha)	Total Marked (M)	Total Number (N)	Probability of Survival (PHI)	Number joining (B)	S.E.(N)	S.E.(PHI)	S.E.(B)	Component of S.E.(N)	Component of S.E.(PHI)
1971	JUNE	1		0.00		0.9446			0.0648			0.0316
	JULY	2	0.3258	46.29	142.08	0.9446	5.69	15.78	0.0641	14.17	14.88	0.0599
	AUG	3	0.7079	95.68	135.17	0.6559	56.02	11.32	0.0645	8.88	9.68	0.0475
	SEPT	4	0.5455	77.84	142.71	0.7318	63.18	12.55	0.0665	12.03	10.60	0.0519
	OCT	5	0.5152	82.58	160.30	0.7657	46.13	15.44	0.0714	13.47	13.66	0.0602
	NOV	6	0.5747	93.10	161.99	0.8067	49.63	16.76	0.0643	14.55	14.88	0.0766
	DEC	7	0.5745	101.73	177.08	0.5938	74.60	19.65	0.0652	12.99	17.95	0.0492
1972	JAN	8	0.4500	78.21	173.81	0.8897	93.15	15.75	0.0947	23.52	13.58	0.0909
	FEB	9	0.5054	122.07	241.55	0.7172	82.47	31.60	0.955	25.11	30.50	0.0884
	APRIL	10	0.4530	111.93	247.10	0.5492	29.04	31.46	0.0685	15.90	30.10	0.0561
	MAY	11	0.5647	88.38	156.50	0.6672	57.15	18.17	0.0713	13.61	15.69	0.0568
	JUNE	12	0.5055	79.65	157.56	0.7950	30.89	16.83	0.0787	12.07	14.58	0.0688
	JULY	13	0.6087	88.76	145.81	0.7695	34.93	15.47	0.1223	13.17	13.07	0.1156
	AUG	14	0.6271	86.00	137.14			23.07			21.63	
	SEPT	15	0.5000									